Implementation Of Supervisory Control And Data Acquisition (SCADA) Functions For The Sudan National Grid

By
Hisham Hassan Ibrahim

Supervisor: Dr. Abdul Rahman Ali Karrar

A Dissertation Submitted
In Partial Fulfillment Of The Requirements For The Degree
Of MS.c In Electrical Engineering

Department Of Electrical Engineering
Faculty Of Architecture And Engineering
University of Khartoum
July 2001

المقدمة

إن عملية إدخال نظم المراقبة والتحكم الرقمية إلى البنية الأساسية للشبكة القومية للكهرباء لا تقتصر علي تطوير عملية نقل و إيصال قراءات الكميات الكهربائية من مختلف مواقع الشبكة الكهربائية إلى مركز التحكم، بل تمتد لتسهم في عملية التحكم بالشبكة من خلال الصورة الواضحة لموقف الإمداد الكهربائي التي يمكن توفيرها، كذلك تساعد في خفض تكلفة الإنتاج من خلال الاحتفاظ بمصادر وفقا لضوابط السلامة بالشبكة و ادني مستوي التوليد الحراري والغازي عند الاستفادة منها في لحظات الذروة ورفع مستوي التوليد المائي إلى أقصي درجة ممكنة. كذلك ومن خلال المعلومات التحليلية و الإحصائية التي توفرها تقارير هذه الأنظمة تسهل عملية دراسة التوسعات المستقبلية.

تهدف هذه الدراسة من خلال التطبيق العملي إلى تقيم أثر إدخال أنظمة التحكم ونقل المعلومات المركزية في تحسين الأداء بالشبكة القومية للكهرباء. وذلك بتصميم نظام مبسط باستخدام أجهزة الكمبيوتر والاستفادة في تقنية الاتصالات وفقا لأسس أنظمة التحكم وجمع المعلومات المركزية.

من خلال النظام الذي تم تصميمه بمحطة ود البشير التي تم إنجازها كنموذج لمحطات الخط الدائري تم إرسال قراءات المحطة إلى غرفة التحكم المركزية وبمقارنتها بالقراءات الموجودة بغرفة التحكم وجدت مطابقة لها.

خلصت الدراسة إلى إمكانية تطبيق أنظمة التحكم وجمع المعلومات بالشبكة القومية للكهرباء وذلك باستيفاء شروط هذه الأنظمة.

ABSTRACT

The introduction of monitoring and control systems into the infrastructure of the power network at Sudan National Grid will change outdated manual and analogue collection and recording methods of electrical quantities to an automated digital system, leading to better supervision of the network, improving services level, helping in preparing and analyzing future developments, better management of electrical recourses, … etc.

The objective of the experimental work described in this dissertation is to study the viability of applying automated computerized methods to one of the distributed electrical network substations. The effect of computerized monitoring systems was applied and studied at Wad El Basher substation. The experimental work focused on performing an effective data acquisition system and data communication link between field instrument and the central station.

This work shows that within certain design conditions, monitoring of electrical quantities could be performed and simple real monitoring system provides better monitoring and data analysis method compared to traditional methods.

The experimental work carried out through this study conform to the SCADA state of the art as described in various literature sources covering the basic requirements of such a system.

Results generated show real time data update at the central station for a typical time interval. The results indicate the viability of applying SCADA techniques for monitoring and control purposes in the National Grid Network.

ACKNOWLEDGEMENTS

Thanks to God for giving me the health and detemination to complete this work .

I would like to express my sincere gratitude to my advisor, Dr. Abdul Rahman Ali Karrar for his trust and help throughout the duration of my study. His supervision and guidance were essential for the completion of this work .

My appreciations are extended to Dr. Sami Sharif for making him self avalable for me .

Special thanks to the staff of the National Electricity Corporation for there help and guidance .

I appreciate the help of my colleagues, Eng. Ala Eldien M.Suliman, Eng. Esam M.Khaer and Eng.Bisher M.Mergani

Finally, I would like to dedicate this work to my family, my mother, my father, my prother and sister, and my wife, Eglal.Their love, understanding and encouraging made this work easy .

TABLE OF CONTENTS

Acknowledgements ii
Table Of Contents iii
Chapter One : Introduction

1.1 Introduction And Background 1
1.2 SCADA Operation Function 4
1.3 Problem Definition 5
1.3.1 Functions 5
1.3.2 Acquisition 6
2.1.2 Interfaces 6
1.3.4 Communications 6
1.3.5 Software Design 6
1.4 Study Objectives 7
1.5 Study Implementations 7

Chapter Two: Introduction To SCADA

2.1 What Is SCADA ? 9
2.1.1 What Is Telemetry ? 9
2.1.2 What Is Data Acquisition ? 9
2.1.3 What Are The Differences Between SCADA And DCS 9
2.2 Components Of SCADA System 10
2.2.1 Field Instrumentation 11
2.2.2 Remote Station 12
2.2.3 Communication Network 13
2.2.4 Central Monitoring Station (CMS) 13
2.3 Typical System Configuration 14
2.3.1 Point To Point Configuration 14
2.3.2 Point To Multi Point Configuration . 15
2.4 Modes Of Communication 16
2.4.1 Polled System 16
2.4.2 Interrupt System 16
2.5 Project Management 17
2.5.1 Identification 17
2.5.2 Initiation 18
2.5.3 Definition 18
2.5.4 Design 18
2.5.5 Acquisition 18
2.5.6 Project Close Out 19
Chapter Three : SCADA Systems Structure Break Down

3.1 Project Overview 20
3.1.1 Field Instrumentation 21
3.1.2 Remote Station 31
3.1.3 Computer Communication 33
3.14 Central Hardware 50

3.2 Software Consideration 52
3.2.1 Modularization Of Software 52
3.2.1 Real Time Operating System 53
3.2.3 Programming Language 55
3.2.4 Database 55

Chapter Four : Implementation Of SCADA Functions

4.1 Project Needs 58
4.2 Interface And Data Acquisition Card 58
4.2.1 Data Acquisition Card 58
4.3 Analog To Digital Converter 60
4.4 Software Implementation 61
4.5 The Choice Of Programming Language 61
4.5.1 History Of Visual Basic 61
4.5.2 Characteristics 62
4.5.3 Size 62
4.5.4 Development Time 62
4.5.5 Learning Curve 62
4.6 Implementation Of Database Design 62
4.6.1 Content And Naming Convention 62
4.7 Database Manager 64
4.8 Operating System 64
4.9 Man-Machine Interface 65
4.10 Comments 66

Chapter Five : Conclusions And Future Aspects

5.1 Project Evaluation 70
5.2 Introduction Of Monitoring And Control System To The Sudan National Grid 71
5.3 Concluding Statement 72
References 73
Appendixes 74

CHAPTER ONE
INTRODUCTION

1.1 Introduction And Background

Expanding the electricity supply network is an important step in the development of the Sudan National Grid infrastructure. The need of electric power as source of energy has greatly grown through the recent years and will continue to increase day by day by leaps and bounds to meet both domestic and industrial needs. This fact faces us with the problem of determining which technology we must develop and use to best manage this resource in a way that will ensure reliable supply even in critical situations. Proper management of the resources would require real time access to information and development of the art of monitoring and control for the power network. This technology must be automated to replace outdated manual supervisory methods.

Performing supervision duties with the aid of computerized systems will make a major change in upgrading execution methods from a tedious manual analogue recording nature to an automated digital analytical control system; that helps in controlling the power network . At site proper monitoring could be achieved directly since site computer RTU (Remote terminal unit) contains data acquisition elements, allowing correction action to be taken at proper time. At the center a global view of the power network recent conditions is obtained helping in over viewing the overall power process.

Additionally (the future of application development lies in standardized distributed components where the service or application

logic can reside within its own site and be located on centralized service) [refer to reference no (3)].

Power monitoring and control are not necessary only to ensure reliable and secure production only but also to: -

- Reduce power cost by using available economic resources (such as hydro stations) to full extent when available and keeping thermal resources at minimum with due consideration to security and other constrains.
- Reduce staffing by reducing number of employees needed to operate and supervise plant.
- Reduce future capital requirements since statistical reports are available for future development studies.

- Improve level of service since unexpected incidents and critical situations are monitored at an early stage.

Historically supervisory control was related to the electrical power process since early days of electrification to monitor and control this widely geographical spread process. Whatever the process size large or small monitoring and control is needed. In its simple case the process is equipped with some kind of measuring device for monitoring purposes and some kind of actuating (executing) device for control purposes.

As a process grows to include several measuring and control devices, it is grouped together on a control panel or MIMIC board, which help in achieving an overall global view of the process. Traditional control rooms, as seen in Figure (1.1.a) consist of MIMIC board that represent a schematic model of the system combined with a control desk. The MIMIC board grows with the size and complexity of the process ; see figure (1.1.b) . Although rebuilding mimic boards technology has became simplified, it does not provide an economical solution or flexible technology for a constantly changing process. Electrical power networks are always a subject to continual change (new lines, new stations etc.) consequently

MIMIC boards will become more complex, cluttered and hard to overview, affecting the monitoring and control efficiency function.

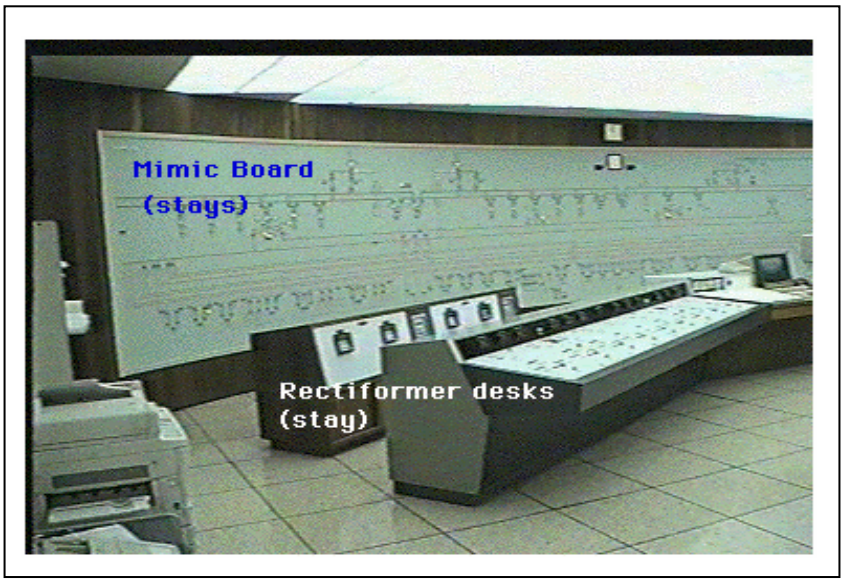


Figure (1.1.a) mimic board combined with a control desk

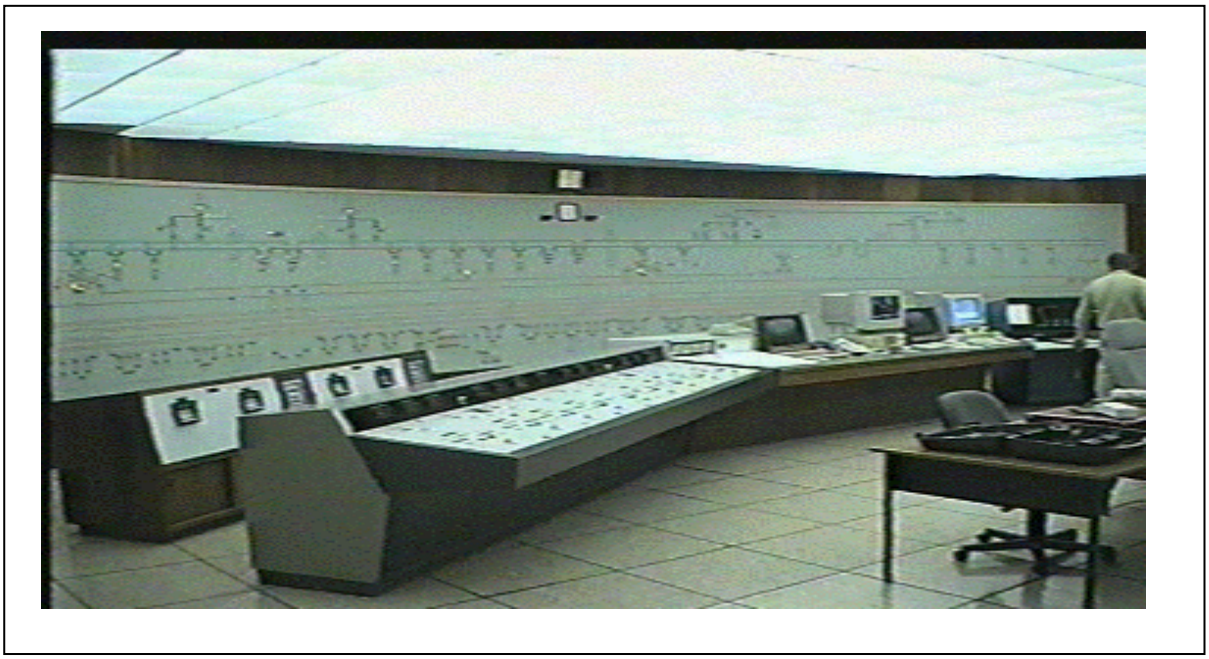


Figure (1.1.b) mimic board combined with a control desk size grows with the process .

In the late 1960s focus of attention was on replacing this inflexible technology with real time computing. Integrating real time computers into control centers result on performing all signal processing in a simple way, and replacing MIMIC board with a visual display unit (VDU); see Figure (1.2). Nowadays control rooms combine both (VDU) display and high level stylized MIMIC models to offer a quick view of the process.

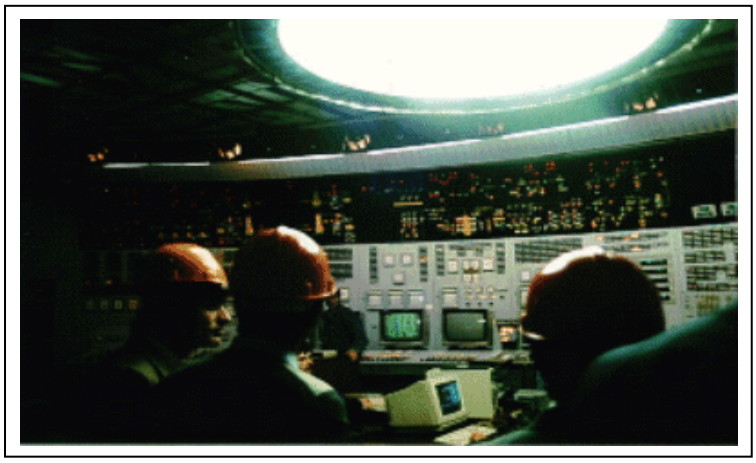


Figure (1.2) mimic board with a visual display unit (vdu)

As power systems increased in size of consumption and complexity, they were followed with development of high performance supervision functions by means of reliable computerized monitoring and control.

Computerized supervisory control system have been 20 years in operation at power utilities, establishing a common set of basic functions which are referred to as SCADA (Supervisory Control and Data Acquisition) functions. The trend of developing SCADA functions has clearly been to establish a standardized system concept that can be adapted to the needs of and provide variations for different utilities. SCADA system is a general hardware and software concept providing a flexible set of functions; the actual use of the SCADA system is specified

by parameters defined in the database. This brings down system costs and increases system reliability. SCADA functions can be summarized as follows: (collection and processing of data, monitoring and handling these data, enabling the control system to influnce the power process, both automatically and on demand, with different control functions)[refer to reference no (10)].

1.2 SCADA Operation Functions

Determining and defining the operation of a power system depends on the system characteristics in terms of production, transmission, distribution and consumption. The control and monitoring of each utility follows strict rules .The operation on the control panel is directly affected by the following operations: -

- Short-term operation plan, which varies from a few hours up to a few months. This operation plan involves planning of production resource utilization and load forecasting as well as contingencies forecasting.
- Instantaneous operation. This involves monitoring of power generation, loads and voltage as well as checking/reacting to transmission of thresholds, protection system action and equipment failures.
- Operation reporting and direct follow up of disturbance.

Actual operation of power system falls on one of four states; the normal state, the alert state, the emergency state and the restoration state. The main goal of the operation is to keep the normal state as long as possible, by detecting any movement against the alert state and bring the system back to its normal state.

The total capacity of high voltage power network that allows the transmission of power from the generation plant to users/consumers plant is determined in terms of the stability characteristics of the system. The control center then monitors the active power load situation and prepares the system to withstand possible contingencies. Control center is highly involved in maintaining the voltage level and its profile throughout the network by monitoring it and switching reactive compensating equipment in and out. Automating the power production process through monitoring and control gives a clear view about power generation, loads, voltages and checking/reacting to transgressions of thresholds, production system action and equipment failures.

1.3 Problem Definition

During the last decade, hundreds of computerized control centers herebeen in operation in different countries; representing the use of computers in power system control in a variety of applications in plant

systems and various generating stations such as hydro and thermal; control centers on various hierarchical positions in power transmission, control centers for distribution
as well as computerized load management applications, at the same time they represent a variety of technical design ranging from complex multiprocessor configuration with hundreds of stations connected to the control center, to the use of small personal computers with only a few stations connected to it.

Hierarchical control centers are today more common than some years ago. Control rooms in large systems is not a single room but is geographically spread out, i.e. operator work places (consoles) are connected to the computerized control center from different remote locations. The main computers are always assisted by one or more front-end computer or "intelligent" communication interfaces based on microcomputers performing the data acquisition.

The impelementation of SCADA functions have yet to be realized in the Sudanese National Grid (NG) , which still employs the traditional Mimic Board concept , some limited basic control functinality has been integrated in to the Mimic boards , but it falls a long way short of fully computerized SCADA implementation . it is envisaged that application of SCADA function to the NG would greatly enhance the operational practices towards greater reliability and controllability .

The functional scope of this research is to define and establish methods to SCADA functions to Sudan Grid.

1.3.1 Functions

The basic problem of concern in such type of projects is the collection and storage of data; by collecting and storing data it is meant that , once the basic mechanism for acquiring and processing the collected data is obtained, this data is to be transferred to a central system together with the collection time. Thus the remote terminal unit (RTU) must be designed to serve a central system by acquiring data from a number of inputs . This problem further more is broken down to sub problems that must be faced and managed to perform the overall task.

1.3.2 Acquisition

Analog data may either be found in volts or milliamps with a tendency towards the latter. The technique applied in collecting analog variables involves multiplexing and an analog to digital (A/D) conversion using an A/D converter connected to RTU bus via the multiplexer. A/D

superimpose higher frequency components which , if they were not filtered out, would cause an erroneous analog value after the A/D conversion. The overall accuracy of the analog input system depends on how the collected analog values can be preserved during the conversion from analog to digital form.

Thus the accuracy of the input circuits and multiplexers, the resolution and accuracy of A/D converter and the efficiency of the filtering applied determine the accuracy of the data aquried .

1.3.3 Interfaces

The equipment for acquisition must be connected to the control system via the input/out (I/O) interface that perform one of the main parts of the RTU, without perfectly operating interface equipment, the data received will be erroneous. The I/O interface must be always designed to withstand a harsh electrical environment. Noise and transients on the incoming signals must be eliminated to avoid input circuit malfunction as well as damage to the circuit board. Proper isolation, grounding and clipping or limiting circuits are the key elements in dealing with this problem.

1.3.4 Communications

Remote control always faces the problem of transmitting data or information over some distance to the central system since communication with the center system is a natural part of the RTUs. Available communication channels are very limited and this can be over come in future development by using lease line.

1.3.5 Software design

RTU functional contents are determined by how the software realizes the function that is to be implemented. Software complexity varies with the functional content of RTU. The main feature that must be obtained in this kind of software in its simple case is to request the I/O interfaces and then store the data collected. The critical design consideration at this point is software reliability and security.

1.4 Study Objectives

With the aid of SCADA functions and microprocessor technology The objectives of the study can be summarized as follow: -

I- Design a monitoring and reporting system.
II- Designing monitoring software.
III-Establishing communication methods.

1.5 Study Implementations

This project was carried out at one of the Khartoum ring substation namely at Wad El Basher substation.

The station interconnected two lines *(*line 1 Khartoum north*,* line 1 forest), with future provisions for extension line 2. The station contain two distributed transformers and control panels that shows the electrical reading of each transformer at the 110 kV side, 33 kV side and 11 kV side.

The substation uses two methods to follow up the station operation the first operation depends on a direct manual recording process for the analogue meters, the second method depends on sending electrical quantities to the control center through a carrier frequency. Appendix A shows the substation layout wiring connections to the transducer used to convert electrical readings to (0 –20) m Amps output standard signals.

This research attempts to develop a standardized monitoring and control to provide the bases for monitoring and controlling the power process .The methods used to carry out the above objectives depends on combining interfacing systems with standard computer PC power and communication power. These systems can be integrated to create a complex and powerful knowledge based control system.

Using a standardized digital system means that costly and secondary technology can be replaced with economically viable solutions. The interface control is built from a general propose components that are common to application. The advantage of modern microprocessor technology makes it possible to realize complex systems with just a few standard modules. The working configuration of modules and devices is no longer achieved by hard wiring only, but also by soft ware modules that provide flexible and quick setup and management.

As this project was carried out at Wad El Basher substation, then the control and monitoring system was structured to be compatible with the control level hierarchy of the sub station, i.e. to combine input/output units for both the centeral control level and the sub station control level with the master unit PC work station for monitoring and control.

The research discuss the subject through :

Chapter One : Introduction :

This chapter include a brief history about control centres and introduces the resarch problem and methodologies .

Chapter Two: Introduction To SCADA:

This chapter discusses the concepts of the supervisory control and data acquisition systems.

Chapter Three : SCADA Systems Structure Break Down:

This chapter provides a unified view of the broad field of supervisory control and data acquisition system (SCADA).

Chapter Four : Implementation Of SCADA Functions:

The ambitious purpose of this chapter is to describe the research steps in building the plan of the state of the art of the national Grid monitering system .

Chapter Five : Conclustins And Future Aspects :

This chapter discusses the research conclutions and the expected future developments that may be obtained by introducing SCADA systems to the (NG) infrastructure .

CHAPTER TWO

INTRODUCTION TO SCADA

This chapter defines SCADA terminology and discusses the concepts of this technology.

2.1 What Is SCADA?

SCADA (Supervisory Control And Data Acquisition) system refers to the combination of telemetry and data acquisition. It consists of collecting information, transferring it back to a central site, carrying out necessary analysis and control, and then displaying this data on a number of operator screens. The SCADA system is used to monitor and control a plant or equipment. Control may be automatic or can be initiated by operator commands.

2.1.1What Is Telemetry?

Telemetry is usually associated with SCADA systems. It is a technique used in transmitting and receiving information or data over a medium. The information can be measurements, such as voltage, speed or flow. These data are transmitted to another location through a medium such as cable, telephone or radio. Information may come from multiple locations. A way of addressing these different sites is incorporated in the system.

2.1.2 What Is Data Acquisition?

Data acquisition refers to the method used to access and control information or data from the equipment being controlled and monitored. The data accessed are then forwarded onto a telemetry system ready for transfer to the different sites. They can be analog and digital information gathered by sensors, such as flowmeters, ammeters, etc. It can also be data to control equipment such as actuators, relays, valves, motors, etc.

2.1.3 What Are The Differences Between SCADA And DCS?

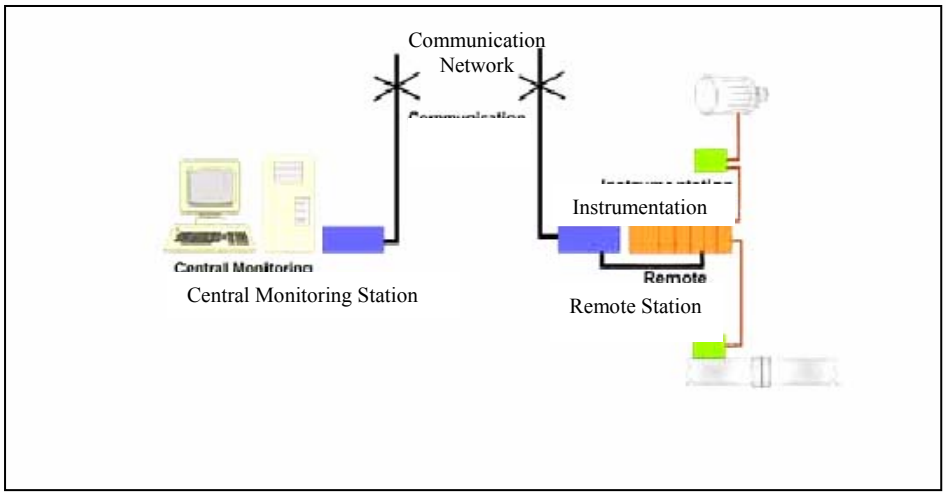
Similar to the SCADA systems are the Distributed Control Systems (DCS). The DCS is usually used in factories and located within a more confined area. It uses a high-speed communications medium, such as local area network (LAN). A significant amount of closed loop control is present on the system .The SCADA system covers larger geographical areas. It may rely on a variety of

communication links such as radio and telephone. Closed loop control is not a high priority in this system.

2.2 Components of SCADA System

A SCADA system is composed of the following: -

1. **Field Instrumentation**
2. **Remote Stations.**
3. **Communications Network.**
4. **Central Monitoring Station.**



Field Instrumentation refers to the sensors and actuators that are directly interfaced to the plant or equipment. They generate the analog and digital signals that will be monitored by the Remote Station. Signals are also conditioned to make sure they are compatible with the inputs/outputs of the RTU or PLC at the Remote Station.

The Remote Station is installed at the remote plant or equipment being monitored and controlled by the central host computer. This can be a Remote Terminal Unit (RTU) or a Programmable Logic Controller (PLC).

The Communications Network is the medium for transferring information from one location to another. This can be via telephone line, radio or cable.

The Central Monitoring Station (CMS) refers to the location of the master or host computer. Several workstations may be configured on the CMS, if necessary. It uses a Man Machine Interface (MMI) program to monitor various types data needed for the operation. The following is a sample configuration of a SCADA system for power process.

Figure (2.1) components of SCADA system

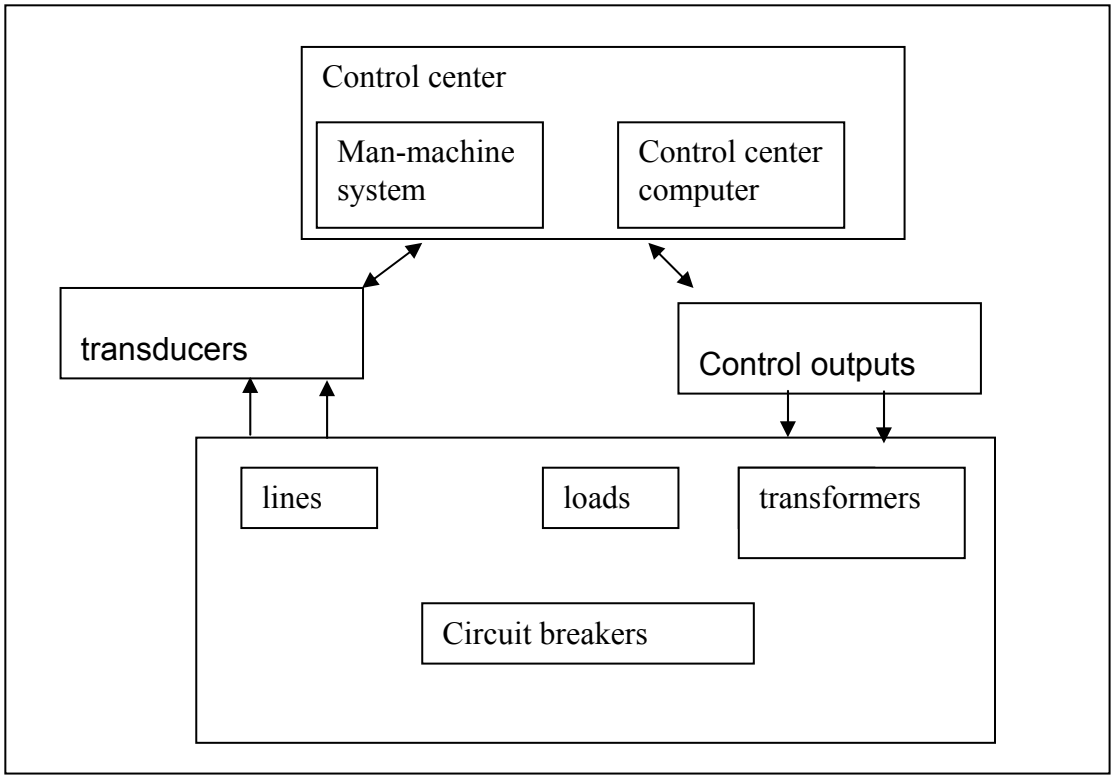


Figure (2.2) SCADA System for a power process

2.2.1 Field Instrumentation

Field Instrumentation refers to the devices that are connected to the equipment or machines being controlled and monitored by the SCADA system. These are sensors for monitoring certain parameters; and actuators for controlling certain modules of the system.

These instruments convert physical parameters (i.e., fluid flow, velocity, fluid level, electrical measurement etc.) to electrical signals (i.e., voltage or current) readable by the Remote Station equipment. Outputs

can either be in analog (continuous range) or in digital (discrete values). Some of the industry standard analog outputs of these sensors are 0 to 5 volts, 0 to 10 volts, 4 to 20 mA and 0 to 20 mA. The voltage outputs are used when the sensors are installed near the controllers (RTU or PLC). The current outputs are used when the sensors are located far from the controllers.

Digital outputs are used to differentiate the discrete status of the equipment. Usually, <1> is used to mean EQUIPMENT ON and <0> for EQUIPMENT OFF status.

Actuators are used to turn on or turn off certain equipment. Likewise, digital and analog inputs are used for control. For example, digital inputs can be used to turn on and off modules on equipment, while analog inputs are used to control a motor speed.

2.2.2 Remote Station

Field instrumentation connected to the plant or equipment being monitored and controlled are interfaced to the Remote Station to allow process manipulation at a remote site. It is also used to gather data from the equipment and transfer them to the central SCADA system. The Remote Station may either be an RTU (Remote Terminal Unit) or a PLC (Programmable Logic Controller). It may also be a single board or modular unit.

2.2.2.1 RTU Versus PLC

The RTU (Remote Terminal Unit) is a terminal computer with very good communication interfacing. Radio interface is used in situations where cable communications are more difficult or unavailable. One disadvantage of the RTU is its poor programmability. However, modern RTUs are now offering good programmability comparable to PLCs.

The PLC (Programmable Logic Controller) is a small industrial computer usually found in factories. Its main use is to replace the relay logic of a plant or process. Today, the PLC is being used in SCADA systems due its very good programmability. Earlier PLC's had no serial communication ports for interfacing to the communication network for transferring of data. Nowadays, PLC's have extensive communication features and a wide support for popular radio units being used for

SCADA system. In the near future we are seeing the merging of the RTU's and the PLC's.

2.2.2.2 Single Board Versus Modular Unit

The Remote Station is usually available in two types, namely, the single board and the modular unit. The single board provides a fixed number of input/output (I/O) interfaces. It is cheaper; but does not offer easy expandability to a more sophisticated system .The modular type is an expandable remote station and more expensive than the single board unit. Usually a backplane is used to connect the modules. Any I/O or communication modules needed for future expansion may be easily plugged in on the back-plane.

2.2.3 Communication Network

The Communication Network refers to the communication equipment needed to transfer data to and from different sites. The medium used can either be cable, telephone line or radio.

The use of cable is usually implemented in a factory. This is not practical for systems covering large geographical areas because of the high cost of the cables, conduits and the extensive labor in installing them.

The use of telephone lines (i.e., leased or dial-up) is a cheaper solution for systems with large coverage. The leased line is used for systems requiring on-line connection with the remote stations. This is expensive since one telephone line will be needed per site. Besides, leased lines are more expensive than ordinary telephone line. Dial-up lines can be used on systems requiring updates at regular intervals (e.g., hourly updates). Here ordinary telephone lines can be used. The host can dial a particular number of a remote site to get the readings and send commands.

Remote sites are usually not accessible by telephone lines. The use of radio offers an economical solution. Radio modems are used to connect the remote sites to the host. An on-line operation can also be implemented on the radio system. For locations wherein a direct radio link cannot be established, a radio repeater is used to link these sites.

2.2.4 Central Monitoring Station (CMS)

The Central Monitoring Station (CMS) is the master unit of the SCADA system. It is in charge of collecting information gathered by the remote stations and of generating necessary action for any event detected. The CMS can have a single computer configuration or it can be networked to workstations to allow sharing of information from the SCADA system.

A Man-Machine Interface (MMI) program will be running on the CMS computer. A mimic diagram of the whole plant or process can be displayed on-screen for easier identification with the real system. Each I/O point of the remote units can be displayed with corresponding graphical representation and the present I/O reading. Set-up parameter limits, etc. are entered on this program and downloaded to the corresponding remote units for updating of their operating parameters.

The MMI program can also create a separate window for alarms. The alarm window can display the alarm tag name, description, value, trip point value, time, date and other pertinent information. All alarms will be saved on a separate file for later review.

A trending of required points can be programmed on the system. Trending graphs can be viewed or printed at a later time. Generation of management reports can also be scheduled on for a specific time of day, on a periodic basis, upon operator request, or event initiated alarms.

Access to the program is permitted only to qualified operators. Each user is given a password and a privilege level to access only particular areas of the program. All actions taken by the users are logged on a file for later review.

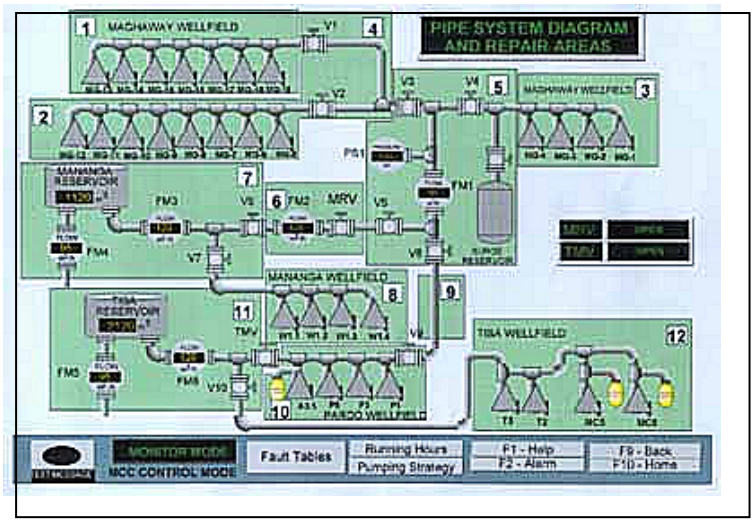


Figure (2.3) MMI Screen

2.3. Typical System Configurations

There are two typical network configurations for the telemetry based SCADA systems. They are the point-to-point and the point-to-multi point configurations.

2.3.1 Point-to-Point Configuration

The Point-to-Point configuration is the simplest set-up for a telemetry system. Here data is exchanged between two stations. One station can be set up as the master and the other as the slave. An example is a set-up of two RTUs: one for a reservoir or tank and the other for a water pump at a different location. Whenever the tank is nearly empty, the RTU at the tank will send an EMPTY command to the other RTU. Upon receiving this command, the RTU at the water pump will start pumping water to the tank. When the tank is full, the tank's RTU will send a FULL command to the pump's RTU to stop the motor.

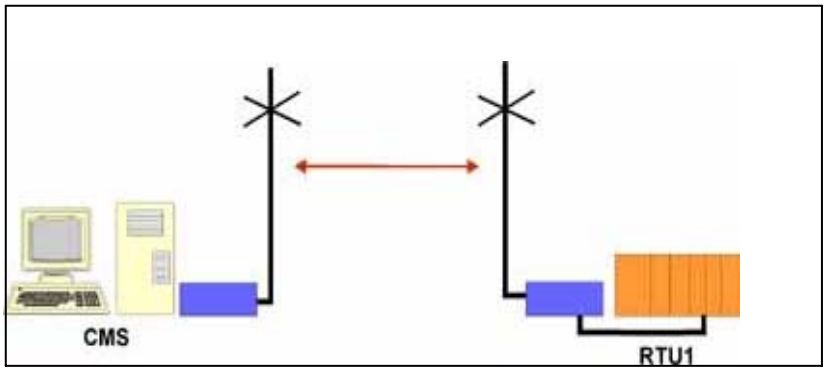


Figure (2.4) Point-to-Point Configuration

2.3.2Point-to-Multipoint Configuration

The Point-to-Multi point configuration is where one device is designated as the master unit to several slave units. The master is usually the main host and is located at the control room, while the slaves are the remote units at remote sites. Each slave is assigned a unique address or identification number.

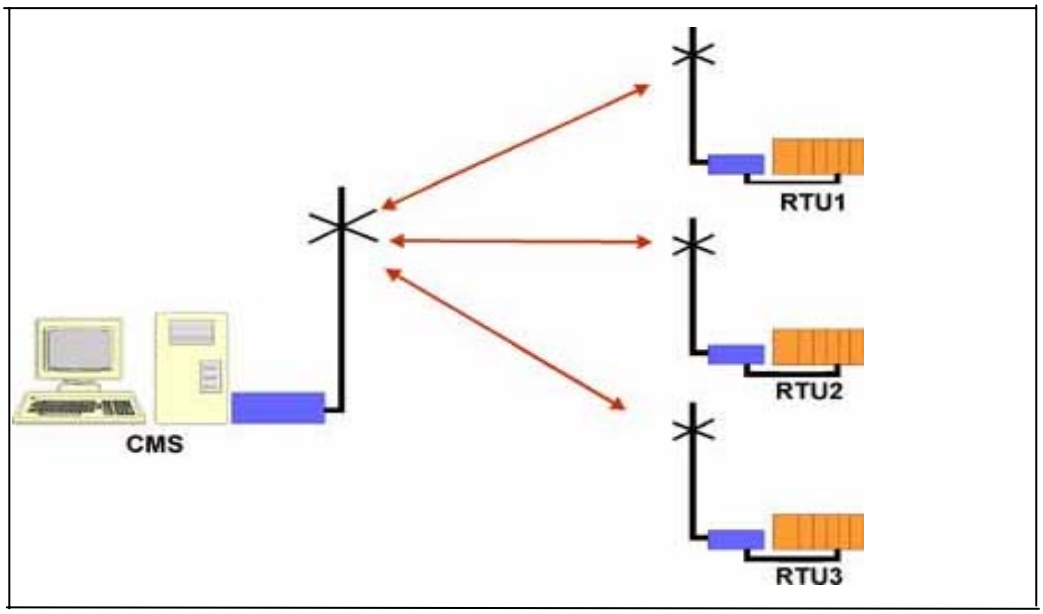


Figure (2.5) point-to-multi Point Configuration

2.4 Modes Of Communication

There are two modes of communication available, namely, the polled system and the interrupt system.

2.4.1 Polled System

In the Polled or Master/Slave system, the master is in total control of communications. The master makes a regular polling of data (i.e., sends and receives data) to each slave in sequence. The slave unit responds to the master only when it receives a request. This is called the half-duplex method. Each slave unit will have its own unique address to allow correct identification. If a slave does not respond for a predetermined period of

time, the master retries to poll it for a number of times before continuing to poll the next slave unit.

Advantages:

- Process of data gathering is fairly simple.
- No collision can occur on the network.
- Link failure can easily be detected.

Disadvantages:

- Interrupt type request from a slave requesting immediate action cannot be handled immediately.
- Waiting time increases with the number of slaves.
- All communication between slaves have to pass through the master with added complexity.

2.4.2 Interrupt System

The interrupt system is also referred to as Report by Exception (RBE) configured system. Here the slave monitors its inputs. When it detects a significant change or when it exceeds a limit, the slave initiates communication to the master and transfers data. The system is designed with error detection and recovery process to cope with collisions. Before any unit transmits, it must first check if any other unit is transmitting. This can be done by first detecting the carrier of the transmission medium. If another unit is transmitting, some form of random delay time is required before it tries again. Excessive collisions result to erratic system operation and possible system failure. To cope with this, if after several attempts, the slave still fails to transmit a message to the master, it waits until polled by the master.

Advantages:

- System reduces unnecessary transfer of data as in polled systems.
- Quick detection of urgent status information.
- Allows slave-to-slave communication.

Disadvantages:

- Master may only detect a link failure after a period of time, that is, when system is polled.
- Operator action is needed to have the latest values.
- Collision of data may occur and may cause delay in the communication.

2.5 Project Management

When designing a SCADA project certain methods must be taken to manage this project. Project Management methodologies involve breaking a project down into phases, usually with approval gate-ways at the end of each phase. A further breakdown into tasks is used to produce a work breakdown structure (WBS).

A typical project management phases of SCADA project include:

- Identification.
- Initiation.
- Definition.
- Design.
- Acquisition.
- Project close out.

2.5.1 Identification

This stage identifies needs and estimate project cost. Plant condition plays a great role in identifying needs, SCADA system is mostly required for reducing power cost and staffing, improving the quality level of service, avoiding unexpected incidents.

2.5.2 Initiation

This stage identifies the main technologies to be used and gaining agreement and approval of the potential users of the system. The emphasis should be on ensuring that there is a common understanding within the end users of what functionality the system will provide.

2.5.3 Definition

At this stage benefits of the system must be identified, and to develop “benefit realization plans” that will identify how the proposed benefits will be realized specifying what changes will be made to the existing process to achieve the intended benefits.

2.5.4 Design

This stage normally involves preparing the specification and developing project evaluation.

Under design and construction, all the detailed work is carried, with number of risk arising . The success of the project will depend on preparing work equipment’s properly. In this stage the project will go through a number of phases. Namely they are:

- **Design.**
- **Configuration of the SCADA master soft ware.**
- **Development of user soft ware.**
- **Assembly of RTU in site.**
- **Field installation of instrumentation.**
- **Communication and RTU’s.**

2.5.5 Acquisition

The basic information with regards to the power system is collected by equipment in the various substation and power plants. This equipment are referred to as data Acquisition elements. At this point data acquisition element specifications are defined to meet the signals level and conditions. Signal conditioning is performed to match the data acquisition input level.

2.5.6 Project Close Out

At this final stage it is important that an assessment be made of how well the system is meeting the organization needs and faults are maintained. It must be mentioned that SCADA functions also provide further development once it has been put in to operation. This is a basic requirement since it must be possible to add new power system components to be monitored and controlled.

CHAPTER THREE

SCADA SYSTEMS STRUCTURE BREAK DOWN

The ambitious purpose of this chapter is to provide a unified view of the broad field of SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM (SCADA). The approach is to break this subject into parts and to build piece-by-piece a plan of the state of the art. The chapter emphasizes basic principles and topics of fundamental importance concerning the architecture of SCADA systems.

3.1 Project Overview

In general SCADA systems can be described as a combination of four main frames or blocks building the over all system.

Namely these are:

- Field instrumentation.
- Remote station.
- Communication network.
- Central monitoring station.

This section will discuss and describe the main points in the developing of the power system SCADA project. Figure (3.1) shows the main SCADA system components.

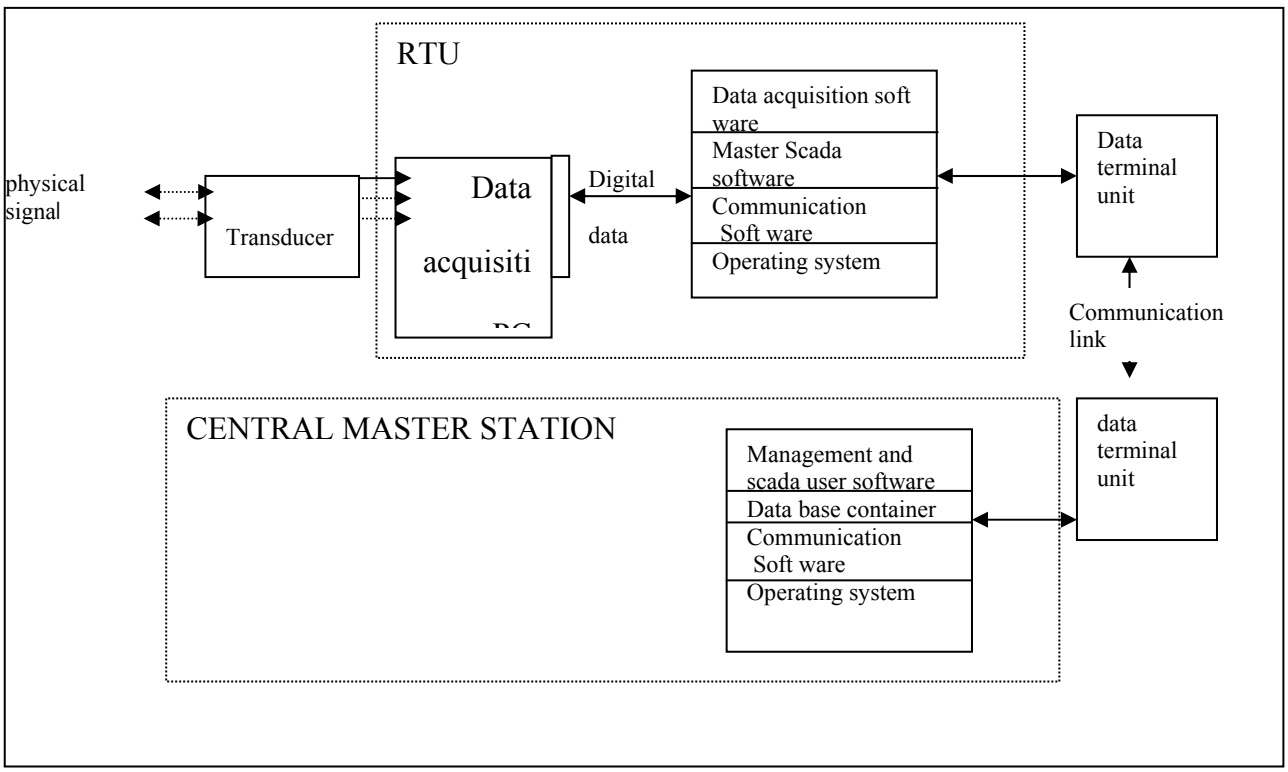


Figure (3.1) A Typical SCADA system block diagram

3.1.1 Field Instrumentation

As mentioned in chapter two, 'field instruments' refers to the equipment that are directly interfaced to the plant or process. They are namely transducers and data acquisition hardware.

3.1.1.1 Transducers

Transducers are devices that convert physical phenomena such as temperature, strain, pressure or light, into electrical properties, such as voltage or resistance. For example, thermocouples and resistance temperature detector (RTDs) converts temperature into voltage or resistance. Other examples include strain gauges, flow transducers, and pressure transducers, which convert force, rate of flow, and pressure to electrical signals. In each case, the electrical signals produced are proportional to the physical parameters they are monitoring.

Thermocouples combine dissimilar metals to generate voltages that vary with temperature.

Other transducers, such as RTDs and strain gauges respond to changes in temperature or strain with varying electrical resistance. These resistance sensors require an accurate exertion current or voltage source to sense the change in resistance.

Many devices or transmitters used in process control and monitoring applications output a current signal, usually 4 to 20 mA or 0 to 20 mA. Current signals are used because they are more immune to errors such as radiated noise and voltage drops on long wire runs. Signal conditioners convert current signals to a voltage signal by passing the input current signal through a precision resistor, see Figure (3.2) the resulting voltage $V_{MEAS} = I_S R$ can then be further conditioned and digitized.

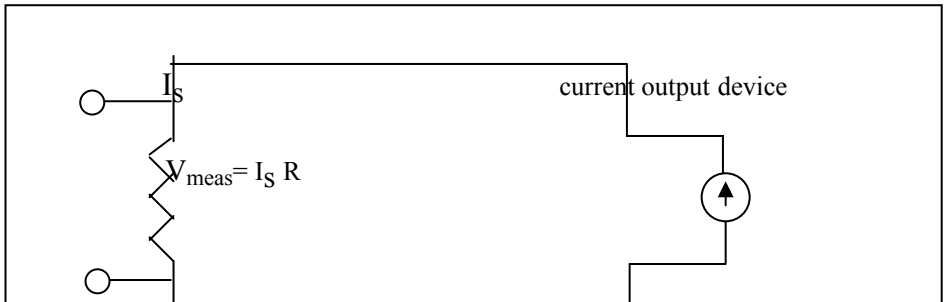


Figure (3.2) process current signals, usually 0 – 20 mA or 4 – 20 mA, are converted to voltage signals using precision resistors.

3.1.1.2 General Signal Conditioning Functions

In addition to handling specific transducer signal, conditioners perform a variety of general purpose conditioning functions to improve the quality, flexibility and reliability of the measurement system.

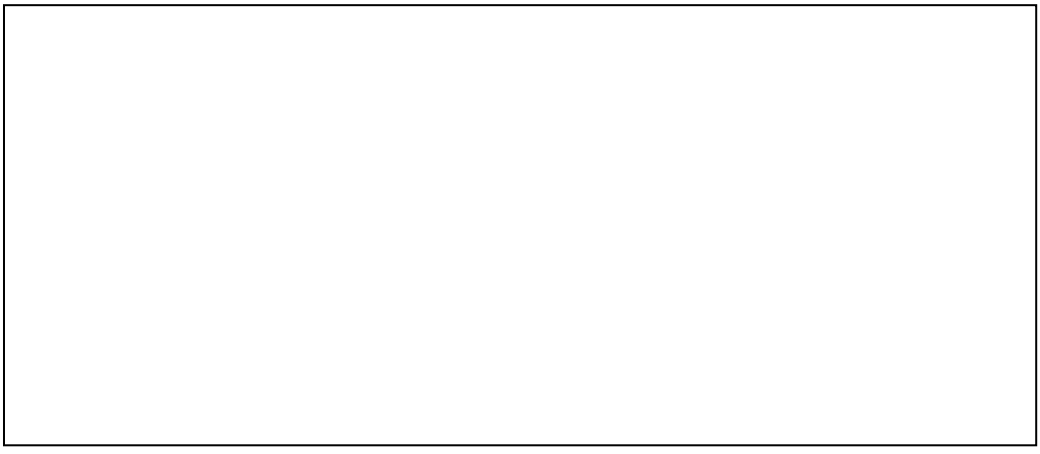
3.1.1.2.a Signal Amplification

Real world signals are often very small in magnitude. Signal conditioners can improve the accuracy of the data. Amplifiers boost the level of the input signal to match for example the range of analog to digital converter (ADC), thus increasing the resolution and sensitivity of the measurement.

3.1.1.2.b Filtering

Filters are used to reject unwanted noise within a certain range. Most data acquisition boards (DAQ) applications are subject to some degree of 50 or 60 Hz noise pick up from power lines or machinery therefore, most conditioners include low pass filters designed specifically to provide maximum rejection of 50 Hz or 60 Hz noise.

Another common use of filters is to prevent signal aliasing a phenomenon that arises when a signal is under sampled (sampled too slowly). Figure (3.3) shows that a higher frequency component is transformed to a lower frequency and cannot be separated from the original raw analog value. The sampling theorem states that: *a signal must be sampled with a frequency at least twice its highest frequency component*. In practice, however, the signal must be sampled more frequently. Signal distortion can be avoided by removing any signal component above one-half the sampling frequency with a low pass filters before the signal is sampled.



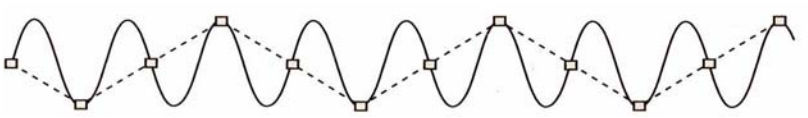


Figure (3.3) higher frequency component is transformed to a lower frequency

3.1.1.2.c Isolation

Improper grounding of the system is one of the most common causes of measurement problems, noise, and damaged DAQ boards. Signal conditioners with isolation can prevent most of these problems. Such devices pass the signal from its source to the measurement device without galvanic or physical connection by using transformer, optical, or capacitive coupling techniques. Besides breaking ground loops, isolation blocks high voltage surges and rejects high common- mode voltage.

3.1.1.3 Data Acquisition Selection Criteria

The analog input specification gives information about the capabilities and accuracy of the DAQ element that to be used in specific process. Basic specifications which are available on most DAQ products, shows the number of channels, sampling rate, resolution and input range. The number of analog channel inputs will be specified for both single ended and differential inputs on boards that have both types of inputs.

Single ended inputs are all referenced to a common ground point. A differential, or non-referenced, measurement system has neither of its inputs tied to a fixed reference. An ideal differential measurement system responds only to the potential difference between two terminals the (+) and (-) inputs, which is referred to as a common mode voltage. The term common-mode voltage range describes the ability of a DAQ board to reject common mode voltage signals.

3.1.1.3.a Sampling Rate

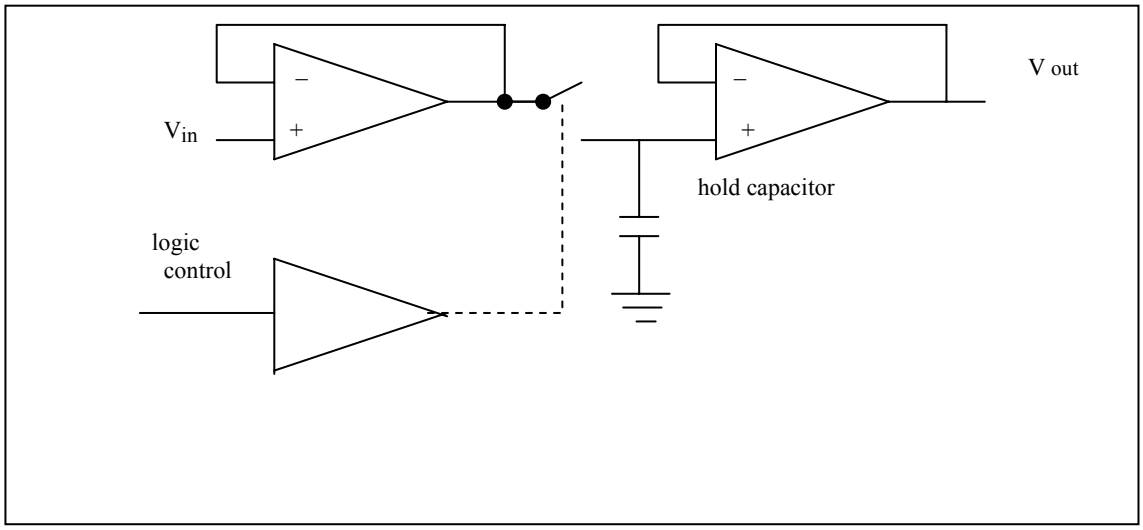
This parameter specifies how often conversion can take place. Using a faster sampling rate, more points in a given time are acquired, providing a better representation of the original signal. As shown in Figure (3.3) all inputs signal must be sampled at a sufficiently fast rate to adequately reproduce the analog signal. Obviously if the signal is changing faster than the DAQ board is digitizing, errors are

introduced into the measured data. In fact, data that is sampled too slowly can appear to be at a completely different frequency as mentioned in section (3.1.1.2.b).

3.1.1.3.b Sampling Methods

When acquiring data from several input channels, analog multiplexers are used to connect each channel signal to an analog to digital converter (ADC) at a constant rate. This method is known as continuous scanning, and it is significantly less expensive than having a separate amplifier and ADC for each input channel.

Because multiplexer switches between channels, a time skew is generated between each channel sample. An analog multiplexer connects one of the inputs to the ADC at a time for digitizing. This method is appropriate for applications where the time relationship between sampled point is unimportant. For applications where the time relationship between inputs is important (such as phase analysis of AC signals) simultaneous sampling is required. Simultaneous sampling elements uses sample and hold circuitry to freeze the signal for each input channel. Simulation of simultaneous sampling hardware can be done to reduce sample-and-hold circuitry. Figure (3.4) shows a sample and hold amplifier. The voltage between the inverting and non-inverting inputs of an op amp is in microvolts that can be approximated to zero.



.

Figure (3.4) sample and hold amplifier

This implies that the voltage from the inverting input (- input) to ground is approximately V_{in}. Because of the direct connection, the output of the first op amp is approximately V_{in} and the first op amp acts like a unity – gain amplifier. The switch is logic controlled, meaning that a high input closes the switch and a low input opens it. When the switch is closed, the capacitor rapidly changes to V_{in}. Since the second op amp is also unity-gain amplifier, V_{out} equals V_{in} to a close approximation. When the switch opens, the capacitor retains its charge. Ideally the output holds at a value of V_{in}.

If the input voltage changes rapidly while the switch is closed, the capacitor can follow this voltage because the charging time constant is very short. If the switch is suddenly opened the capacitor voltage represents a sample of the input voltage at the instant the switch was opened. The capacitor then holds this sample until the switch is again closed and a new sample taken.

Therefore it is important to consider the following factors in the selection of DAQ element.

a) Acquisition Time

Acquisition time is the time needed to get an accurate sample typically to within 0.1 percent after the switch is closed. Ideally acquisition time is zero, but in a real sample and hold amplifier the charging time constant of the hold capacitor plus other factors produce a non-zero acquisition time.

b) Aperture Time

Aperture time is the time required for the switch to open, since the switch is a transistor switch, there is a short time before it appears open and no longer affects the hold capacitor.

c) Drop Rate

The drop rate is the rate at which the output voltages decrease in the hold condition. There are leakage paths for the capacitor charge and this is why the output voltage will drop slowly when the switch is open.

3.1.1.3.C Multiplexing

A common technique for measuring several signals with a single ADC is multiplexing. A multiplexer selects and routes one channel to the ADC for digitizing, and then switches to another channel and repeats. Because the same ADC is sampling many channels, the effective rate of each individual channel is reduced in proportion to the number of channels sampled. External analog multiplexers can be used to increase the numbers of channels a board can measure. Figure (3.5) shows 4 to 1 multiplexer. If the select code is 01, then x_1 appears at the output Y, if the address 11, then $Y = x_3$, etc.

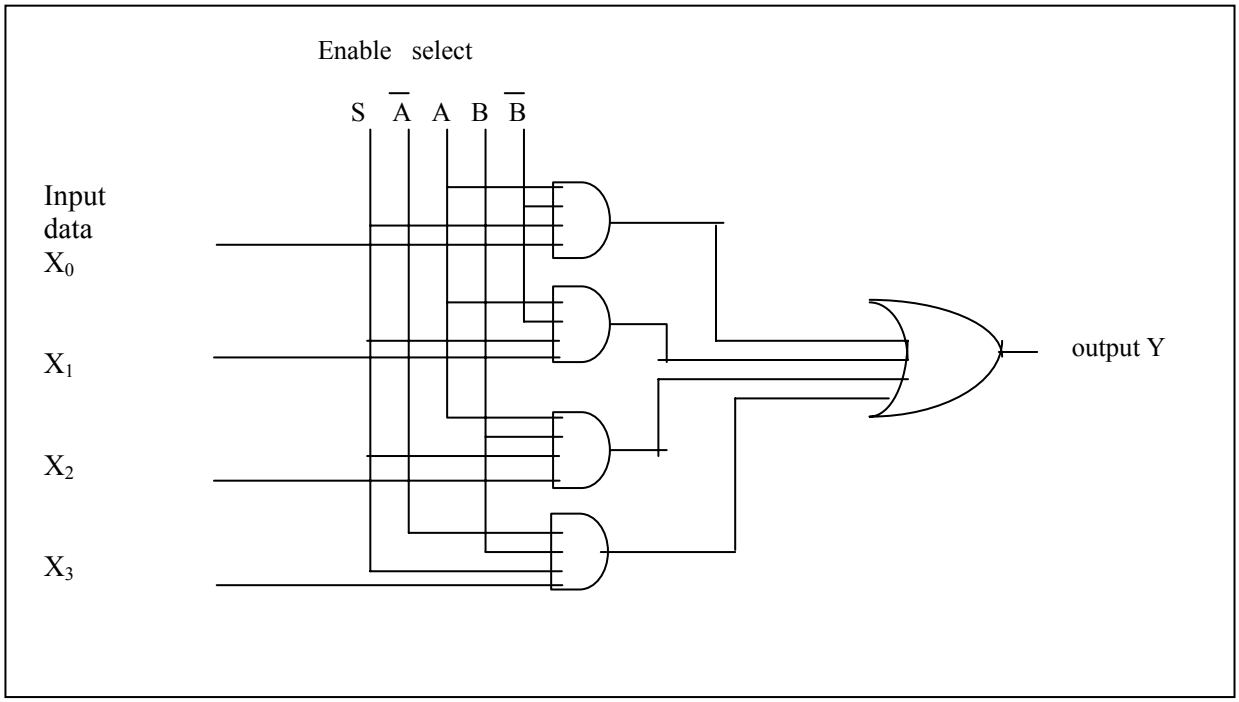


Figure (3.6) A 4 – to 1 line multiplexer

3.1.1.3.d Resolution

The number of bits that the ADC uses to represent the analog signal is called the resolution. The higher the resolution, the higher the number of divisions the voltage range is broken into, and therefore, the smaller the detectable voltages change. Figure (3.6) shows a sine wave and its corresponding digital image as obtained by an ideal 3-bit ADC.

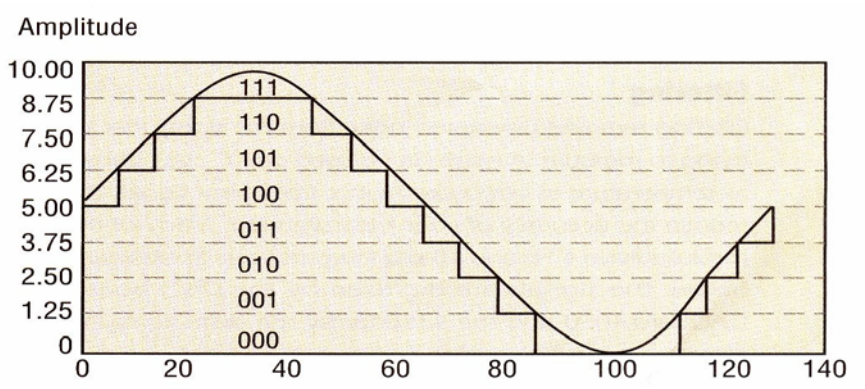


Figure (3.6) sine wave digital image

A 3-bit converter divides the analog range into $_2{}^3$ or 8 divisions. Each division is represented by a binary between 000 and 111. Clearly the digital representation is not a good representation of the original because information can be lost in the conversion. By increasing the resolution to 16 bits however, the number of codes from the ADC increases from 8 to 65,536 obtaining an extremely accurate digital representation of the analog signal.

Analog to digital conversion can be performed using one of the following techniques.

a) A/D Converter Using Counter:

In this circuit a continuous sequence of equally spaced pulses is passed through a gate. The gate is normally closed, and is opened at the instant of the beginning of a linear ramp .The gate remains open until the linear sweep voltage attains the reference voltage of a comparator, at a level set equal to the analog voltage to be converted. The number of pulses in the train that pass through the gate is therefore proportional to the analogue voltage. If the analog data varies with time, it will not be possible to convert the analog data continuously, therefore it will be required that the analog data be sampled at intervals. The maximum value of the analog voltage will be represented by a number of pulses *n*. It is clear that the time interval between two successive pulses shall be larger than the timing error of the time modulator. The recurrence frequency of the pulses is equal, at a minimum to the product of *n* and the sample rate. Actually the recurrence rate will be larger in order to allow time for the circuit to recover between sampling .The principals discussed are shown in the A/D converter at figure (3.7). The clear pulse resets the counter to zero count. The counter then records in binary form the number of pulses from the clock line. The clock is a source of pulses equally spaced in time. Since the number of pulses counted increases linearly with time, the binary word representing this count is used as the input of D/A converter whose out put is shown in figure (3.8). As long as the analog input V_s is greater than V_d, the comparator out put is high and the AND gate is open for the transmission of the clock pulses to the counter, when V_d exceeds V_s the comparator output changes to the low value and the AND gate is disabled. This stops the counting at the time when $V_s = V_d$ and the counter reads out the digital word representing the analog input voltage.

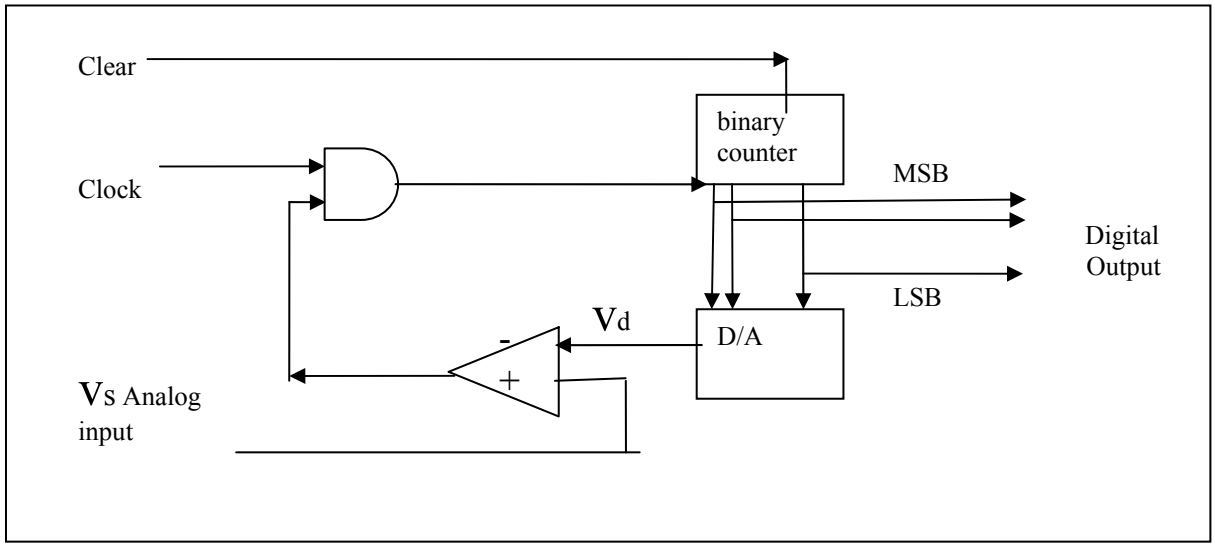


Fig (3.7) A/D converter using a counter

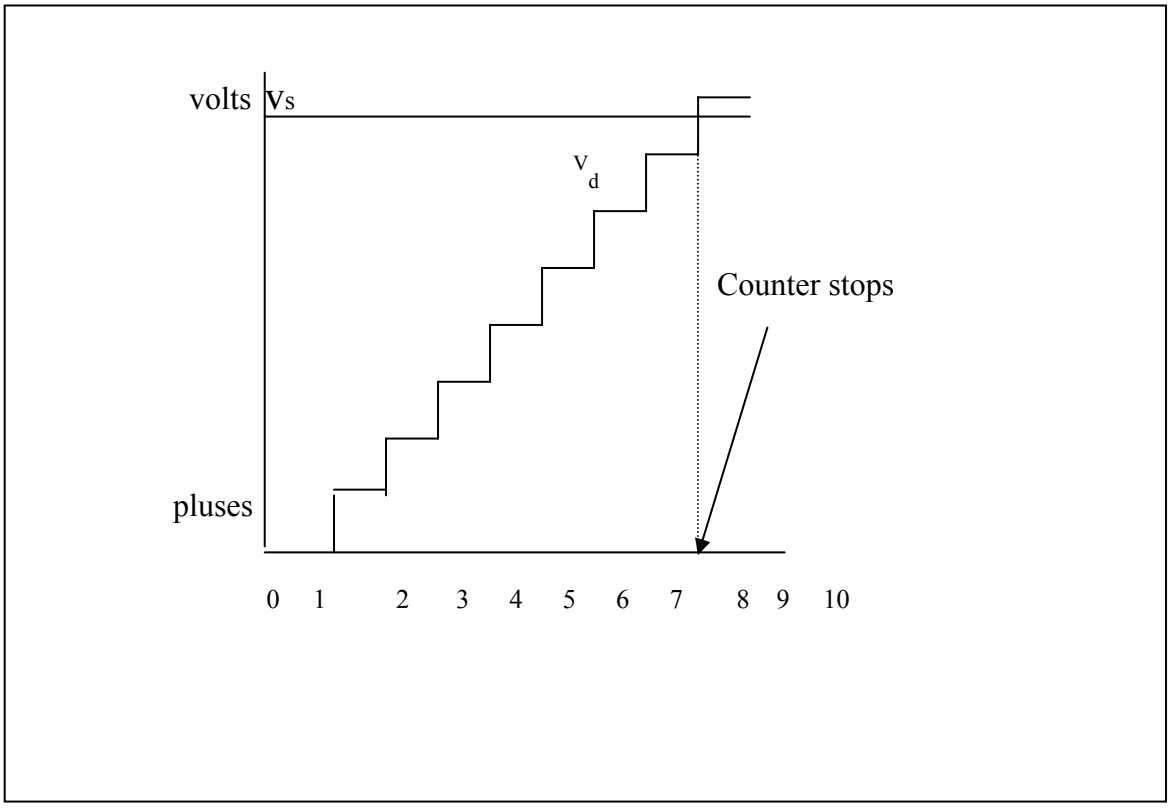


Fig (3.8) A/D converter counter ramp waveform

b) Successive Approximation A/D Converter

Successive approximation technique is another method to implement an A/D converter. Instead of a binary counter as shown in figure (3.7) a programmer is used to set the most significant bit (MSB) to

1, with all other bits to 0, and the comparator compares the D/A output with the analog signal. If the D/A output is larger, the 1 is removed from the MSB, and it tried in the next most significant bit. If the analog input is larger the 1 remains in that bit. Thus a 1 is tried in each bit of the D/A decodes unit, at the end of the process, the binary equivalent of the analog signal is obtained. Figure (3.9) shows the system diagram of successive approximation A/D converter.

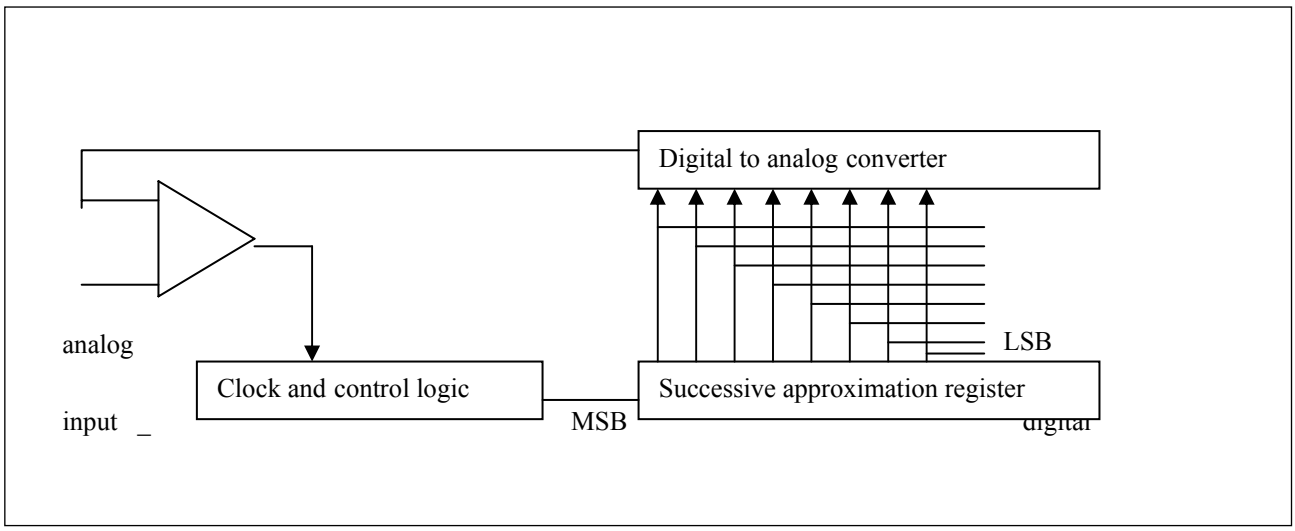
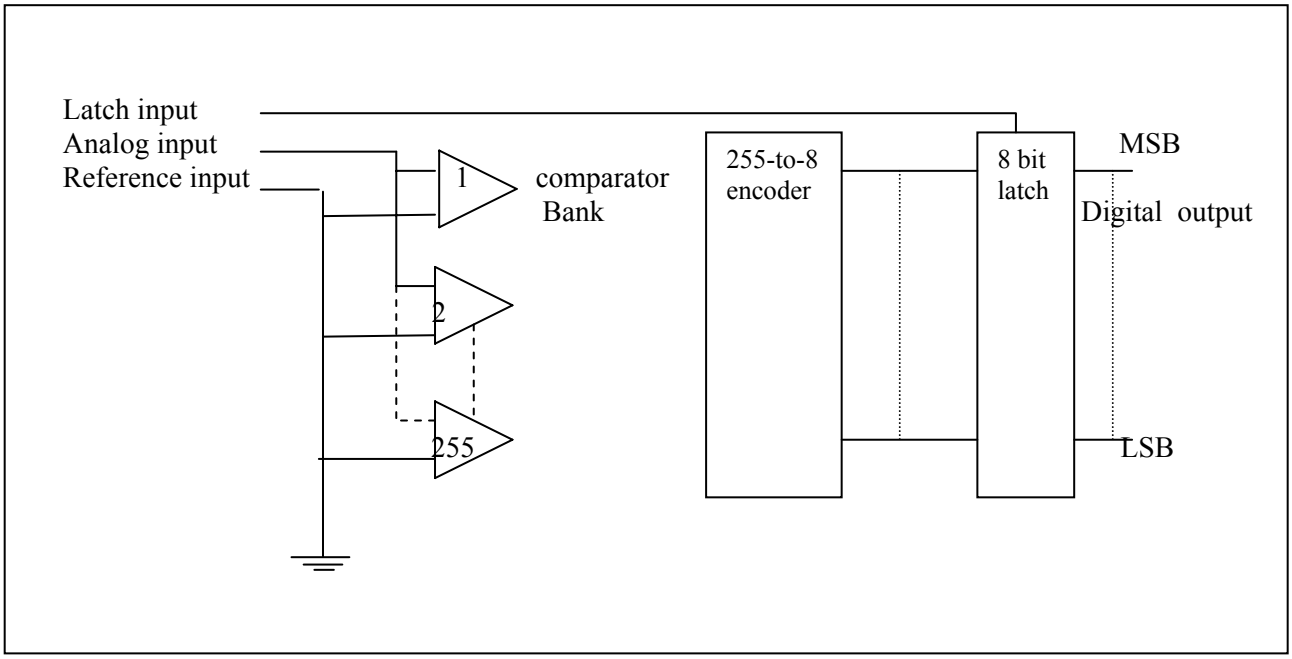


Figure (3.9) Successive approximation A to D converter

c) Flash Conversion

This method of A /D conversion uses an array of 2^{n-1} comparator, to digitize an *n*-bit word. Since only one step is necessary to complete the conversion, this procedure is faster than the counter-ramp and successive approximation method. Figure (3.10) shows 8 bit A/D flash

converter.



3.1.1.3.e Range

Range refers to the minimum and maximum voltage levels that the ADC can span .The range, resolution and gain available on DAQ boards determine the smallest detectable change in voltage. This change in voltage represents 1 LSB of the digital value, and is often called the code width. The ideal code width is found by; dividing the voltage range by the gain times two raised to the order of bits of resolution. For example a 16 bit board with a selectable range of 0 to 10 or -10 to +10V and selectable gain of 1,2,5, 10,20,50 or 100 with a voltage range of 0 to 10V and a gain of 100 the ideal code width is

$$\frac{10\ V}{100 \times 2^{16}} = 1.5\mu\ V$$

Therefore, the theoretical resolution of one bit in the digitized value is 1.5 μV, which represents the minimal measurable value by the ADC *[11]*

3.1.1.3.f Load

It is important to consider what kind of load does DAQ present to the source that it will be sensing? The device must not overload the source and reflect the true value being measured. If this is the case, a unity gain operational amplifier with high input impedance must be added to buffer the input to the device.

3.1.2 Remote Station

Remote terminal as a part of the supervisory control and data acquisition system (SCADA), is installed at the process plant where physical phenomenen are processed to accomplish the SCADA functions. Figure (3.11) shows the main components of this station.

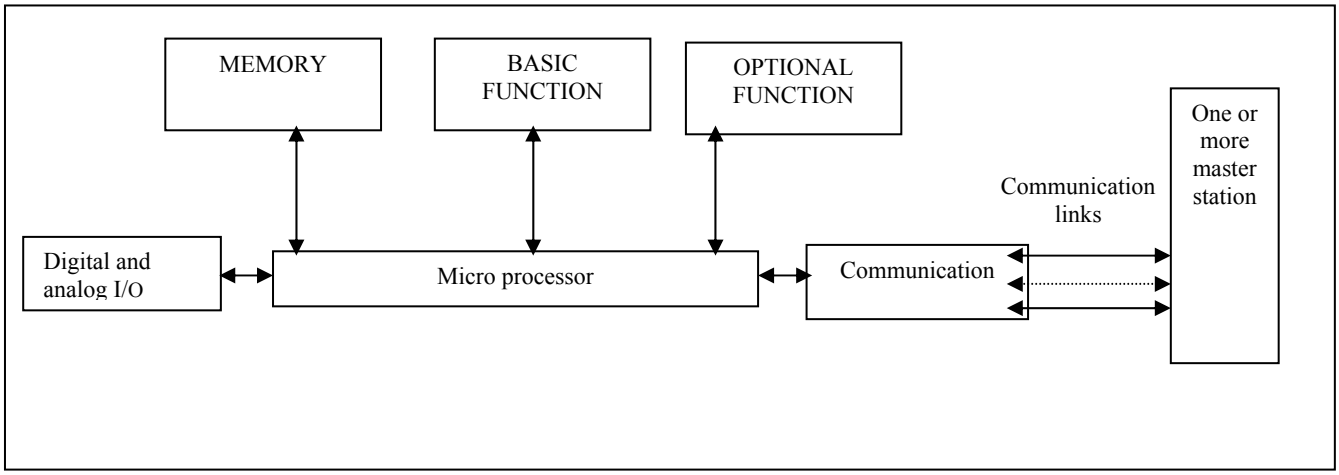


Figure (3.11) RTU block diagram

RTU station perform the following jobs :-

Data Acquisition: This is to deal with various jobs.
- Discrete inputs (single ended & differential)
- Status monitoring
- Pulse counting
- Pulse timing
- Digital inputs

Control Outputs:
- Manually depending on check before continuing
- Automatically depending on software
- Master/remote communication
- Universal commands
- Data transfer

Operational security:
- Minimum of false commands
- Communication errors & data transfer error

Internal Monitoring:
- Manage power failure
- Reference inputs

Since there are a number of different makes of RTU many solutions exist to achieve the RTU functions that varies from single board RTUs containing one or few I/O's up to very large multiprocessor-base RTUs containing hundred or thousand of I/O's. Although the functional content may differ irrespectively of the amount of I/Os connected, there are always typical hardware component in common used. Depending on the size of the RTU and function requirement, hardware elements can be configured in various structures. The RTU hardware consist of the following main units:

a. Central processing unit (CPU).
b. Memory.
c. I/O interface.
d. Communication interface.

In designing RTU the microprocessor and memory can be powered from an IBM compatible computer and by means of input/output interface card the desired signal can be processed. Interfacing any circuit to a computer needs some knowledge about the IBM PC system bus and address. The PC system is available for the attachment of interfacing at card slots on the motherboard. All card slots are bused with identical signals on each pin at TTL logic levels, except for those of the power and ground buses that are provided in the connections. The bus is a de-multiplexed and re-powered super set of the microprocessor bus. For further information and description refer to appendix B.

3.1.2.1 I/O Port Address Decoding Techniques

There are three basic ways to get data into or out of a PC bus; they are called programmed I/O, interrupt driven I/O and direct memory access (DMA). Although

programmed I/O is the slowest of the three it is used in simpler microprocessor systems where speed is unimportant. As the system becomes more complex the interrupt approach becomes necessary. In the most advanced system, DMA is needed because it is the only way to transfer large amount of data in a short time.

The simplest way to decode an I/O port address or group of address for an interface design is to inspect the address space and find a block of unused address, and then construct the proper decode circuitry [*Refer to appendix C for more details*]. There are two timing concerns when decoding a port address. The first is at the beginning of an I/O port bus cycle. If the port address decoded has a lot of delay, data may be written to the wrong port address. The second timing concern is at the end of I/O port bus cycle a delay at this stage may write data to an address that is decoded from the next bus cycle.

3.1.2.2 I/O Port Address Map

The I/O port address map can be divided into two parts. The first part is the address space HEX 0000 – HEX 01FF, or that part which resides on the base system board. These port addresses are used to address the processor support to devices and the integrated I/O on the base system board. It should be noted that HEX address 0000 through 01FF are not used as either input or output ports on the baseboard. For detailed information on the functions of these ports, the IBM Technical Reference manual should be consulted.

The second part of the PC I/O port address space, HEX 0200 through HEX 02FF are used for port address decoded on the system, and care should be made that no two devices use the same address [refer to appendix c].

3.1.3 Computer Communication

Communication plays an essential part in the design of the SCADA system. The combination of computing power with high-speed data communication is rightly regarded as potentially the most powerful influence yet on handling information. Computer communications depends on the following facts:-.

* There is no fundamental difference between data processing (computers) and data communication (transmission and equipment).

* There are no fundamental differences among data, voice and video communications.

* The line between single - processor computer, multi- processor computer, local network, wide area network, and long haul network has vanished.

The fundamental purpose of data communication is to exchange information between two agents. In Figure (3.12), the information to be exchanged is a message labeled m.

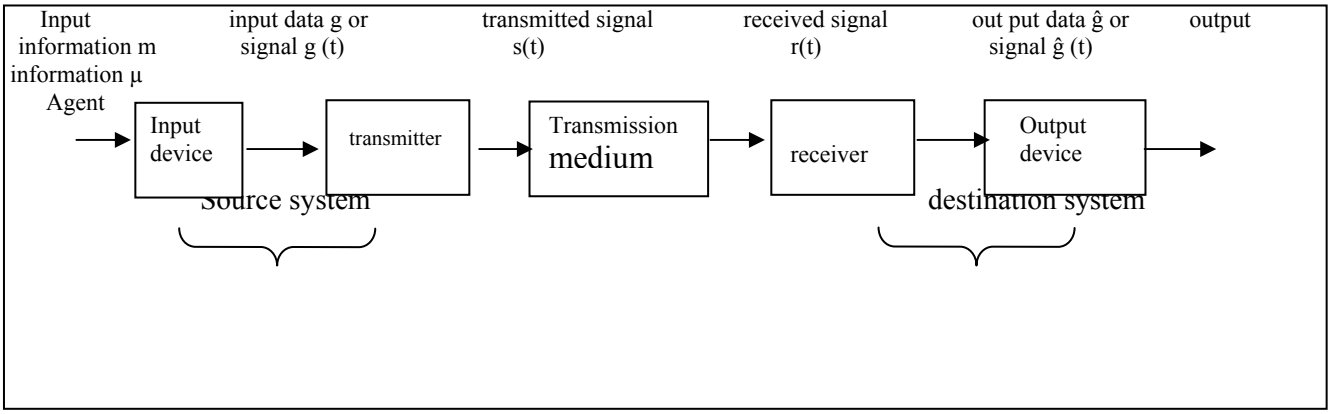


Figure (3.12) simplified communication block diagram

This information is represented as data g and is generally presented to a transmitter in the form of a time-varying signal g (t).

The term Data is a representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation or processing by human beings or by automatic means; but upon all, data can be and should be used, namely for producing information [3].

The signal g (t) is not in a form suitable for transmission and must be converted to a signal s (t) that is in some sense matched to the characteristic of the transmission media. On the other hand after transmission, a signal r (t), which may differ from s (t), is received. This signal is converted by the receiver into a form suitable for output. The converted signal $\breve{g}(t)$ or data $\breve{g}$ is an approximation or

estimate of the input. Finally the output device presents the estimated message μ, to the destination agent.

3.1.3.1 Communications Tasks

In order to transmit information there are many tasks that must be performed in a data communication system, table (3.1) list these tasks.

Transmission system utilization	Routing
Interfacing	Recovery
Signal generation	Message formatting
Synchronization	Protection
Exchange management	***System management***
Error detection and correction	
Flow control	
Addressing	

Table 3.1. Communication task

Transmission system utilization refers to the need to make efficient use of transmission system facilities that are typically shared among a number of communication devices. Various techniques (refered to as multiplexing) are used to allocate the total capacity of a transmission medium among a number of users. Congestion control techniques are required to assure that the system is not overwhelmed by excessive demand for transmission services.

In order to communicate, a device must interface with the transmission system. As an interface is established signal generation is required for communication. The properties of the signal, such as form and intensity, must be such that they are capable of being propagated through the transmission system and interpretable as data at the receiver.

Not only must the signals be generated to conform to the requirement of the transmission system and receiver, but also there must be some form of synchronization between transmitter and receiver. The receiver must be able to determine when a signal begins to arrive and when it ends and also the duration of each signal element.

Beyond the basic matter of deciding on the nature and timing of signals, there are a variety of requirements for communication between two parties that might be collected under the term exchange management, such as exchange of data in both directions over a period of time.

Although error detection and correction might have been included under exchange management, they are important enough to be listed separately because they are required in circumstances where errors cannot be tolerated as in the case of data processing systems.

Flow control is required to assure that the source does not overwhelm the destination by sending data faster than they can be processed and absorbed.

Addressing and routing are related but distinct concepts. When a transmission facility is shared by more than two devices, a source system must somehow indicate the identity of the intended destination. The transmission system must assure that the destination system and only that system receives the data.

Recovery is a concept distinct from that of error correction. Recovery techniques are needed in situations in which an information exchange (data base transaction or file transfer) is interrupted due to a fault somewhere in the system. The objectives either to be able to resume activity at the point of interruption, or at least to restore the state of the systems involved to the condition prior to the beginning of the exchange.

Message formatting has to do with an agreement between two parties as to the form of the data to be exchanged or transmitted.

Frequently it is important to provide some measure of protection in a data communication system to assure security.

Finally, a data communication facility is a complex system that cannot erect or run itself. System management capabilities are needed to configure the system, monitor its status, react to failures and over load, and plan intelligently for future growth.

3.1.3.2 Computer Communications Architecture:

The term data Communication is concerned with the transfer of a signal or set of data between two points; with no regards for the meaning or intent of those data. Similarly, communication networks are concerned primarily with such a data transfer, with no regards for data content; even so the following tasks must be performed.

1. The source system must either activate the direct data communication path or inform the communication network of the identity of the desired destination system.
2. The source system must ascertain that the destination system is prepared to receive data.
3. The information exchange application on the source system must ascertain that the information exchange management program on the destination system is prepared to accept and store it.
4. If the formats used on the two systems are incompatible, one of the two systems must perform a format translation function.

To perform the above jobs for computer communications and computer networks, two concepts are paramount.

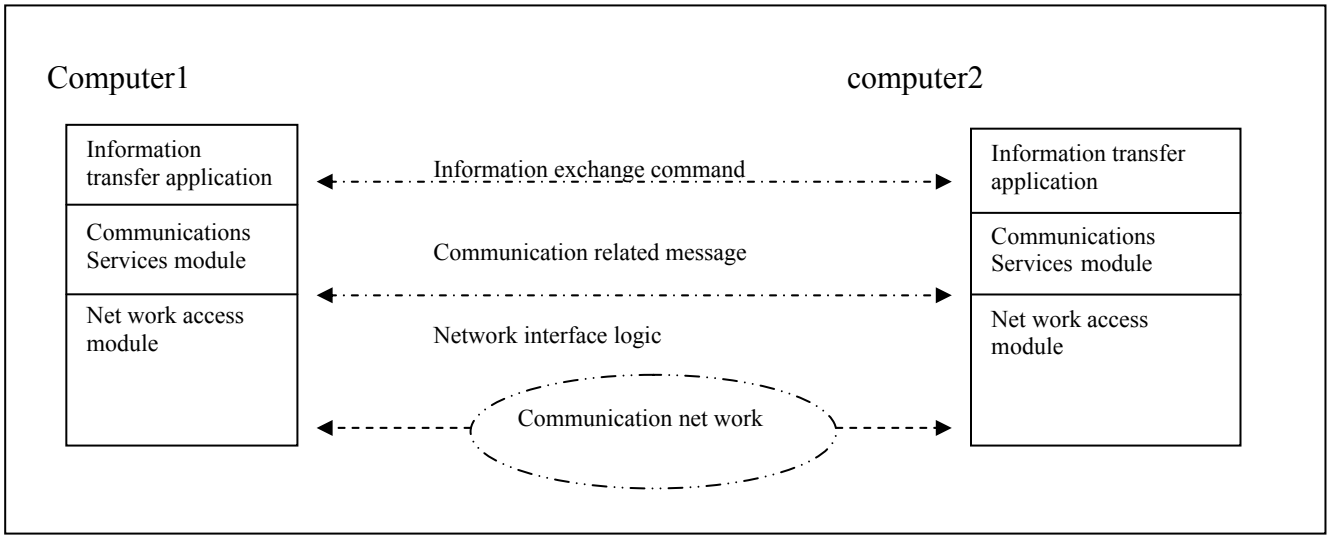
- Protocols
- Computer - communication architecture

A protocol is used for communication between entities in different systems. An entity is anything capable of sending or receiving information, and a system is a physically distinct object that contains one or more entities. For two entities to communicate successfully, they must speak the same language, what is communicated, how it is communicated, and when it is communicated they must conform to some mutually acceptable conventions between the entities involved. The conventions are referred to as a protocol, which may be defined as a set of rules governing the exchange of data between two entities.

The key elements of a protocol are:

- Syntax : includes such things as data format and signal levels.
- Semantics: includes control information for coordination and error handling.
- Timing : includes speed matching and sequencing.

In order to perform a high degree of cooperation between the two computers, the task is broken up into sub tasks, each of which is implemented separately. As an example Figure (3.13) suggests the way in which a file transfer facility could be implemented through three modules are used.



To summarize the motivation of the three-module the information exchange module contains all the logic that is unique to the exchange application, such as (transmitting passwords, commands and records). To ensure reliable transmission, the communication service module is concerned with assuring that the two computer systems are active and ready for data transfer and for keeping track of the data that are being exchanged to assure delivery. These tasks are independent of the type of network that is being used. Therefore, the logic for actually dealing with the network is separated out into a separate network access module. Therefore if the network to be used is changed, only the network access module is affected. Thus, instead of a single module for performing communications, there is

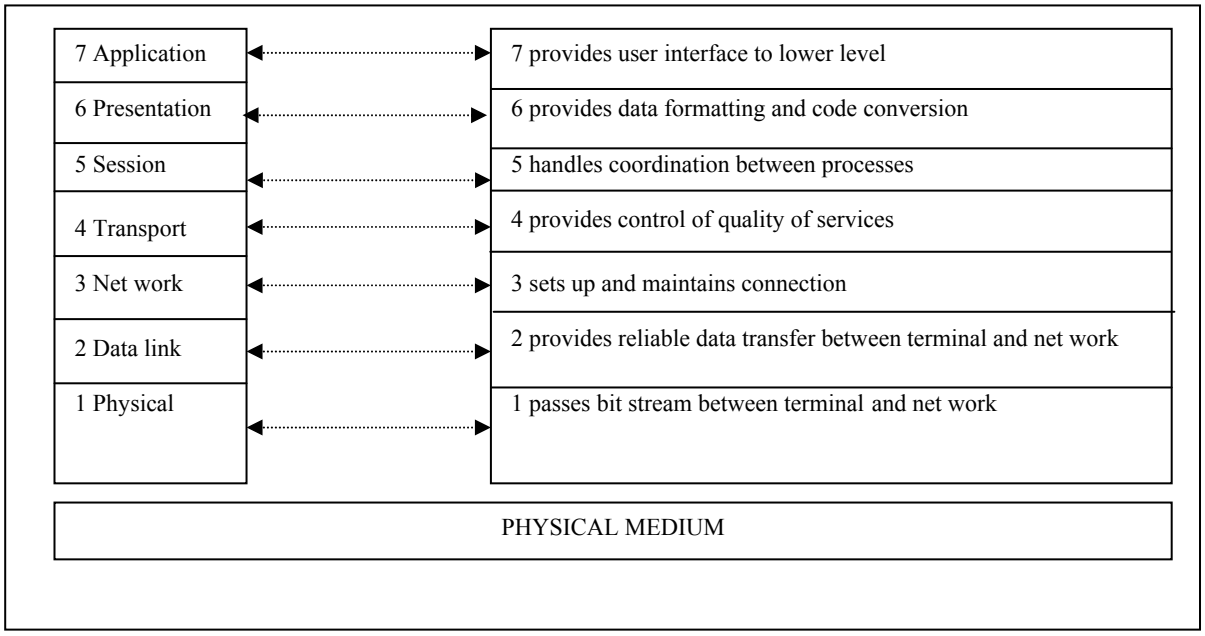
a structured set of modules that implements the communication function. That structure is referred to as communication architecture.

3.1.3.3 The OSI Model

Figure (3.13) suggests that the various elements of the structure set of protocols are layered, or form a hierarchy. This concept if also evident in figure (3.14), which depicts the open system interconnection (OSI) model. The OSI model was developed by the international organization for standardization as a model for computer communication architecture, and as a framework for developing protocol standards.

3.1.3.4 The OSI Layers

1. Physical: Concern with transmission of unstructured bit stream over physical medium, deals with the mechanical, electrical, functional, and procedural characteristics to access the physical medium.
2. Data link: Provides for the reliable transfer of information across the physical link; sends block of data (frames) with the necessary synchronization, error, control, and flow control.



3. Network: Provides upper layers with independence from the data transmission and switching technologies used to connect systems; responsible for establishing; maintaining, and terminating connections.
4. Transport: Provide reliable, transport transfer of data between end points; provides end-to-end error recovery and flow control.
5. Session: Provides the control structure for communication between applications; establishes; manages; and terminates connections (sessions) between cooperating applications.
6. Presentation: Provides independence to the application processes from difference in data representation (syntax).
7. Application: Provides access to the OSI environment for users and also provides distributed information services.

Successful transmission of data depends principally on two factors: the quality of the signal being transmitted, and the characteristics of the transmission medium.

3.1.3.5.1 Transmission Terminology

Data transmission occurs between transmitter and receiver over some transmission medium. Transmission media may be classified as guided or unguided. In both cases, communication is in the form of electromagnetic waves. With guided media, the waves are guided along a physical path; for example twisted pair, coaxial cable and optical fiber. Unguided media provide a means for transmission of electromagnetic waves but do not guide them, examples are propagation through air vacuum and sea water. A guided transmission medium is point-to-point if it provides a direct link between two devices and those are the only two devices sharing the medium in a multi point guided configuration, more than two devices share the same medium, refer to Figure (3.15.a) and (3.15. b).

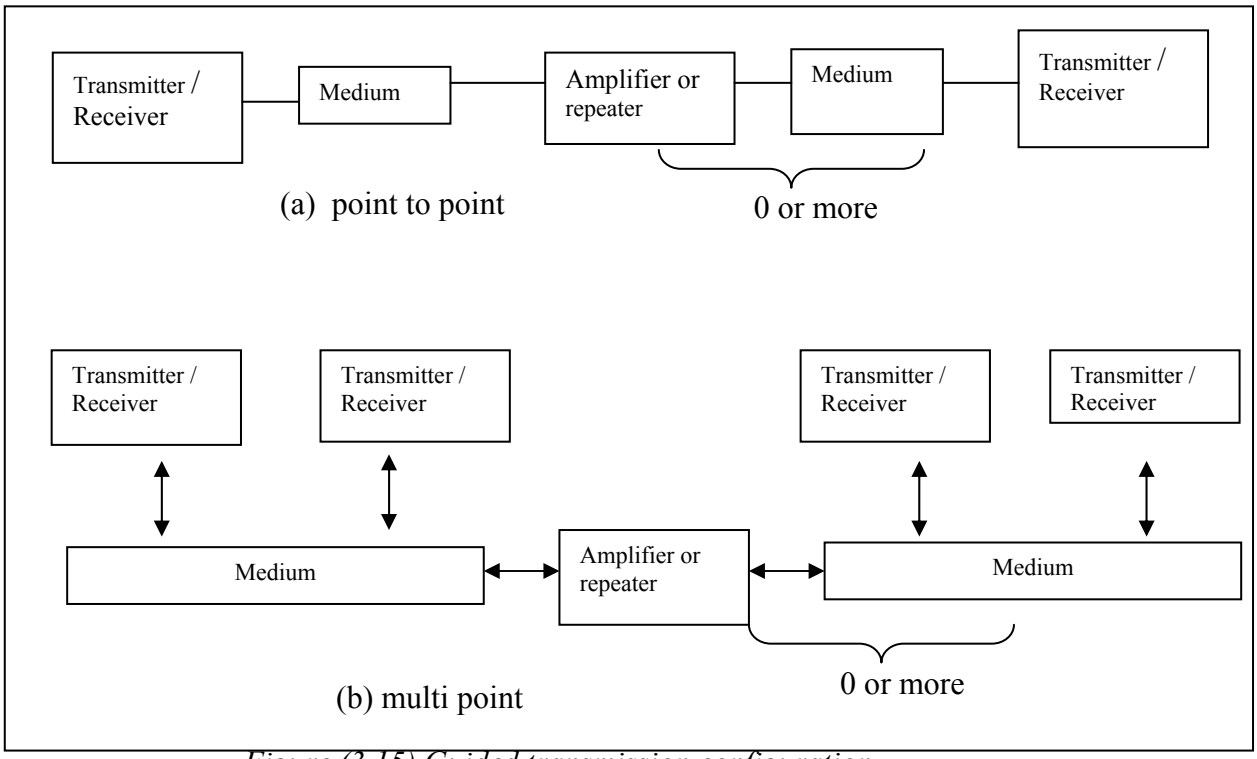


Figure (3.15) Guided transmission configuration

When data is transmitted from a source to a destination communication systems are concerned with the nature of the data, the actual physical means used to propagate the data and what processing or adjustment may be required along the way to assure that the received data are intelligible. Great care must be made to the point whether we are dealing with analog or digital entities. The term's analog and digital correspond to continuous and discrete and the two terms are used in three context:

* Data * Signaling * Transmission.

3.1.3.5.2 Data

Analog data take on continuous values on some interval e.g. (voice and video); most data collected by sensors are continuous value such as temperature and pressure. Digital data takes on discrete value examples are text and integers.

3.1.3.5.3 Signals

In a communication system, data is propagated from one point to another by means of electric signals. An analog signal is a continuously varying electromagnetic wave that may be propagated over a variety of media, such as twisted pair, coaxial cable and fiber optic cable. A digital signal is a sequence of voltage pulses that may be transmitted over a medium, for example, a constant positive voltage level may represent binary 1 and a constant negative voltage level may represent binary 0.

3.1.3.5.4 Data And Signals

Analog data is a function of time and occupy a limited frequency spectrum; such data can be represented by an electromagnetic signal occupying the same spectrum. Digital data can be represented by digital signals; with a different voltage level for each of the two binary digits. Digital data can also be represented by analog signals by use of a modem (modulator/demodulator). The modem converts a series of binary voltage pulses into an analog signal by encoding the digital data onto a carrier frequency. The resulting signal occupies a certain spectrum of frequency centered about the carrier and may be propagated across a medium suitable for that carrier. The most common modems represent digital data in the voice spectrum and hence allow those data to be propagated over ordinary voice-grade telephone lines. At the other end of the line, the modem demodulates the signal to recover the original data.

3.1.3.5.5 Transmission

Both analog and digital signals may be transmitted on suitable transmission media. Analog transmission is a means of transmitting analog signals without regard of their content; the signals may represent analog data or digital data. In either case, the analog signal will become weaker (attenuate) after a certain distance to achieve longer distances, the analog transmission system includes amplifiers that boost the energy in the signal. Unfortunately the amplifier also boosts the noise components for analog data, such as a voice, quite a bit of distortion can be tolerated and the data remain intelligible. However for digital data, cascaded amplifiers will introduce errors. Digital transmission, in contrast, is concerned with the content of the signal. A digital signal can be transmitted only a limited distance before attenuation endangers the integrity of the data. To achieve greater distance, repeaters are used. A repeater receives the digital signal, recovers the pattern of 1'S and 0'S and transmits a new signal, over coming the attenuation .The same technique may be used with an analog signal if it is assumed that the signal carries digital data. At appropriately spaced points, the transmission system has repeaters rather than amplifiers. The repeater recovers the digital data from the analog signal and generate a new clean analog signal thus ensuring that noise is not cumulative.

3.1.3.5.6 Transmission Impairments

With any communication system, it must be recognized that the signal that is received will differ from the signal that is transmitted due to various transmission impairments. For analog signals, these impairments introduce various random modifications that degrade the signal quality. For digital signals, bit errors are introduced: A binary 1 is transformed into a binary 0 and vice versa. The most significant impairments are:

3.1.3.5.6.1 Attenuation

The strength of a signal falls off with distance over any transmission medium. For guided media, this reduction in strength, or attenuation, is generally logarithmic and thus is typically expressed as a constant number of decibels per unit distance. For unguided media attenuation is a more complex function of distance and makeup of the atmosphere.

3.1.3.5.6.2 Delay Distortion

Delay distortion is a phenomenon peculiar to guide transmission media. The distortion is caused by the fact that the velocity of propagation of a signal through a guided medium varies with frequency. For a band-limited signal, the velocity tends to be highest near the center frequency and fall off toward the two edges of the band. Thus various frequency components of a signal will arrive at the receiver at different times. This effect is referred to as delay distortion, since the received signal is distorted due to variable delay in its components. Delay distortion is particularly critical for digital data.

3.1.3.5.6.3 Noise

For any data transmission event, the received signal will consist of the transmitted signal, modified by the various distortion imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception, the latter undesired signals are referred to as noise. Noise may be divided into four categories:

Thermal noise: due to thermal agitation of electrons in a conductor.

Inter modulation: noise produced when there is some non-linearity in the transmission system. Normally, these components behave as linear system, that is, the output is equal to the input times a constant, in a nonlinear system, the output is a more complex function of the input. Component malfunction or the use of excessive signal strength can cause such non-linearity.

Cross talk: is an unwanted coupling between signal paths. It can occur by electrical coupling between nearby twisted pair or rarely coaxial cable lines carrying multiple signals.

All of these types of noise so far have reasonably predictable and reasonably constant magnitudes. Thus it is possible to design a system to cope with them.

Impulse noise: is non-continuous noise, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude. It is generated from a variety of causes, including external electromagnetic disturbance such as lightning, and faults and flows in the communications system. Impulse noise is generally only a

minor annoyance for analog data. However, impulse noise is the primary source of error in digital data communication

3.1.3.5.7 Channel Capacity

The rate at which data can be transmitted over a given communication path, or channel under given conditions, is referred to as the channel capacity.

The following concepts are related to one another.

- Data rate: This is the rate in bits per second (BPS), at which data can be communicated.
- Bandwidth: This is the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycle per second, or hertz.
- Noise: The average level of noise over the communication path.
- Error rate: The rate at which errors occur, where an error is the reception of a (1) when a (0) was transmitted or the reception of a (0) when a (1) was transmitted.

3.1.3.5.8 Transmission Media

The transmission medium is the physical path between transmitter and receiver in a data communication system. The characteristic and quality of data transmission are determined both by the nature of the signal and the nature of the medium in the case of guided media, the medium itself is more important in determining the limitation of transmission. Table (3.2) contains typical characteristics for guided media.

Transmission medium	**Total data rate**	**Bandwidth**	**Repeater spacing**
Twisted pair	4 MBPS	250KHz	2-10 KM
Coaxial cable	500 MBPS	350 MHz	1-10 KM
Optical fiber	2 G BPS	2 Ghz	10 - 100 KM

Table (3.2) point-to-point transmission characteristics of guided media.

For unguided media, the spectrum or frequency band of the signal produced by the transmitting antenna is more important than the medium in determining transmission characteristics.

3.1.3.5.8.1 Twisted Pair

A twisted pair consists of two insulated copper wires in a regular spiral pattern. A wire pair acts as a single communication link. The twisting of the individual pairs minimizes electromagnetic interference between the pairs. By far the most common transmission medium for both analog and digital data is twisted pair, it is the backbone of the telephone system as well as the workhorse for inter-building communications. Compared to other transmission media, twisted pair is limited in distance bandwidth, and data rate.

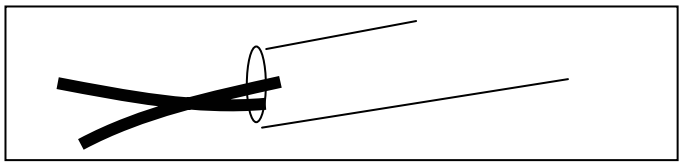


Figure (3.16) twisted pair cable

3.1.3.4.8.1 Coaxial Cable

Coaxial cable consists of two conductors, constructed to permit it to operate over a wider range of frequencies.

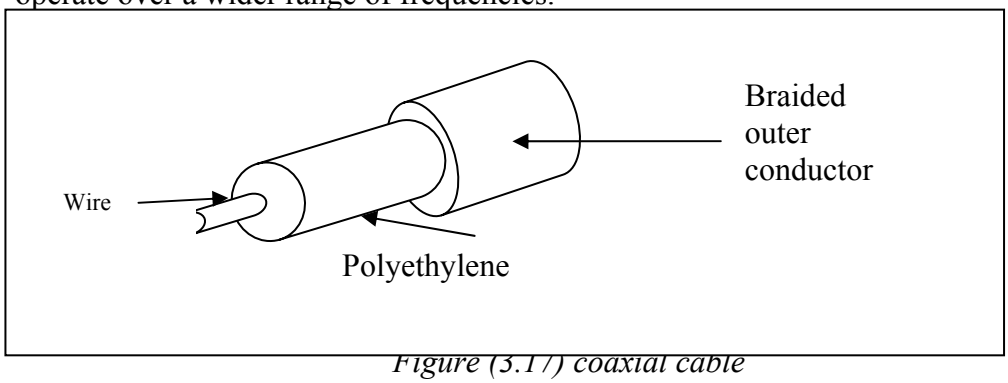


Figure (3.17) coaxial cable

Coaxial cable consists of a hollow outer cylinder conductor that surrounds a single inner wire conductor. Coaxial cable has been perhaps the most versatile transmission medium and is enjoying increasing utilization in a wide variety of applications. Coaxial cable has superior frequency characteristics to twisted pair, and can hence be used effectively at higher frequencies and data rates because of its shielded, concentric construction. Coaxial cable is much less susceptible to interference and cross talk than twisted pair.

3.1.3.5.8.3 Optical Fiber

An optical fiber is a thin (2 to 125 μm) flexible medium capable of conducting an optical rays. An optical fiber cable has a cylindrical shape and consists of three concentric sections: the core, the cladding and the jacket. The core is the inter most section and consists of one or more very thin strands, or fibers, made of glass or plastic. Each fiber is surrounded with cladding, a glass or plastic coating that has optical properties different from those of the core. The outermost layer, surrounding one or a bundle of cladded fibers, is the jacket, which is composed of plastic and other materials to withstand abrasion, crushing and other environmental dangers. The following characteristics distinguish optical fiber from twisted pair and coaxial cable.

- Greater bandwidth.
- Smaller size and lighter weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing

Optical fiber transmits a signal-encoded beam of light by means of total internal reflection. The optical fiber acts as a wave guide for frequencies in the range $_{10}^{14}$ to $_{10}^{15}$ Hz which covers the visible spectrum and part of the infrared spectrum Figure (3.18) shows the principle of optical fiber transmission. Light from a source enters the cylindrical glass or plastic core, rays at shallow angles reflected and propagated along the fiber, other rays are absorbed by the surrounding materials. This form of propagation is called multi mode, referring to the variety of angles that will reflect. When a fiber core radius is reduced, fewer angles will reflect. By reducing the radius of the core to the order of a wavelength only a single angle or mode can pass the axial ray.

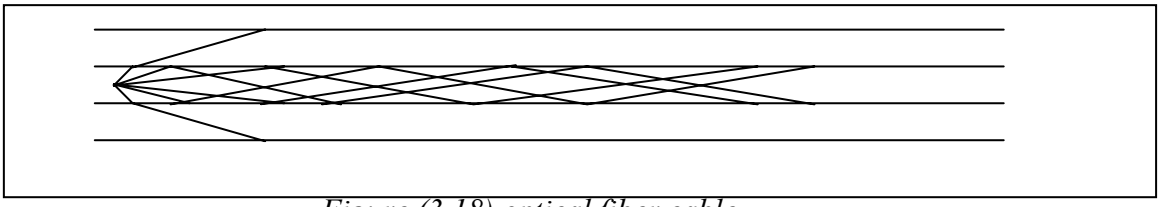


Figure (3.18) optical fiber cable

3.1.3.6 Digital Data Communication Techniques

For two devices linked by a transmission media to exchange data, a high degree of cooperation is required. Data are transmitted one bit at a time over the medium. The timing (rate, duration, spacing) of these bits must be the same for transmitter and receiver. Two common techniques asynchronous and synchronous re used to perform this task.

3.1.3.6.1 Asynchronous And Synchronous Transmission

When speaking about serial transmission of data, data are transferred over a single communication path rather than a parallel set of lines. With serial transmission, signaling elements are sent down the line one at a time. Synchronization is one of the key tasks of data communications.

A transmitter is sending a message one bit at a time through the medium to a receiver. The receiver must recognize the beginning and end of a block of bits. It must also know the duration of each bit so that it can sample the line with the proper timing to read each bit.

3.1.3.6.1.a Asynchronous Transmission

Two approaches are common for achieving the desired synchronization. The first is called asynchronous transmission. This scheme avoids timing problem by not sending long, uninterrupted streams of bits. Data are transmitted one character at a time, where each character is five to eight bits in length. Timing or synchronization must only be maintained within each character, the receiver has the opportunity to resynchronize at the beginning of each new character .The technique is easily explained with reference to Figure (3.19) when no character is being transmitted, the line between transmitter and receiver is in an 'idle' state .

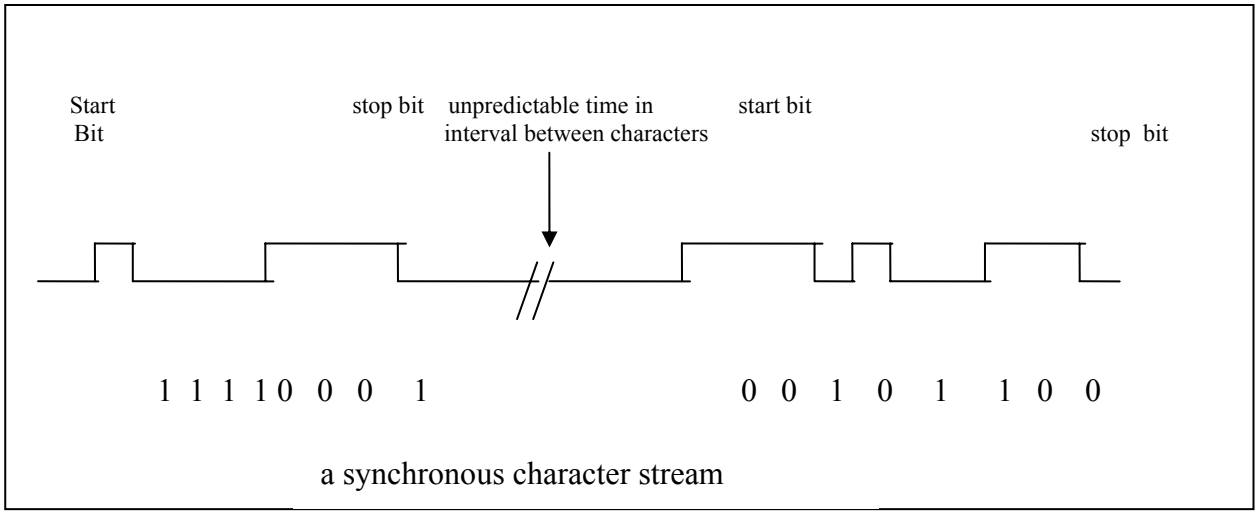


Figure (3.19) Asynchronous transmission

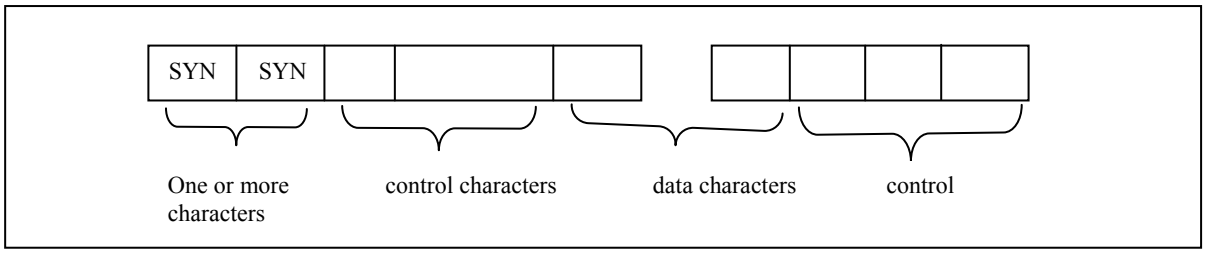
The definition of idle is equivalent to the signaling element for binary1. For most interface standards, idle corresponds to the presence of a negative voltage on the line, the beginning of a character is signaled by a start bit with a value of binary 0, this is followed by five to eight bits that actually make up the character. The bits of the character are transmitted starting with the least significant bit. Usually the character bits are followed by a parity bit, which therefore is in the most significant bit position. The parity bit is set by the transmitter such that the total number of ones in the character, including the parity bit is even (even parity) or odd (odd parity) depending on the convention being used. The final element is a stop bit , which is a binary 1. A minimum length for the stop is specified and it is usually 1,1.5 or 2 times the duration of an ordinary bit. The transmitter will continue to transmit the stop signal until it is ready to send the next character. If a steady stream of characters is send, the interval between two characters is uniform and equal to the stop element. In the idle state, the

receiver looks for a transition from 1 to 0 to begin the next character and then samples the input signal at one bit intervals for seven intervals it then looks for the next 1 to 0 transition, which will occur after one bit a time.

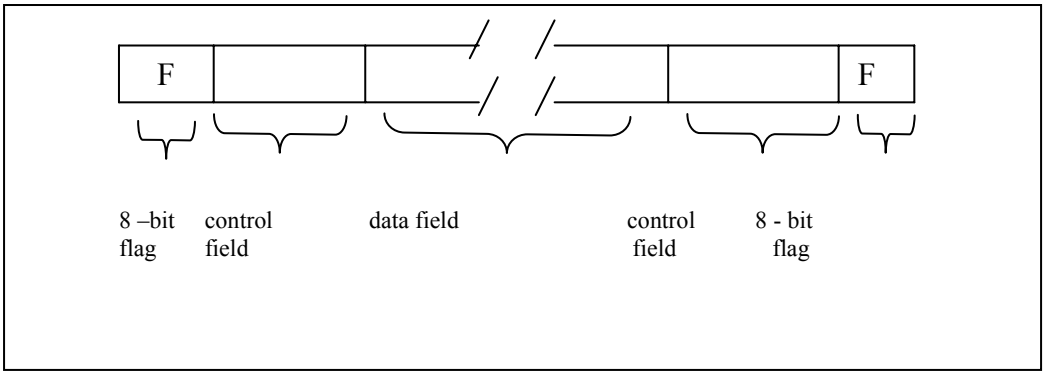
The timing requirements for this scheme are ASCII characters send as 8 - bit units, including the parity bit. If the receiver is slower or faster then the transmitter, the sampling of eighth information bit will be displaced and still be correctly sampled. An error such as this actually results in two errors, first the last sampled bit is incorrectly received. Second the bit count may be out of alignment. If bit 7 is a 1 and bit 8 is a 0, bit 8 could be mistaken for a start bit; this condition is termed a framing error as the character plus start and stop bits are sometimes referred to as a frame. A framing error can also occur if some noise condition causes the false appearance of a start bit during the idle state.

3.1.3.5.1.b Synchronous Transmission

A more efficient means of communication is synchronous transmission. In this mode, blocks of characters or bits are transmitted without start and stop codes. The exact departure or arrival time of each bit is predictable to prevent timing drift between transmitter and receiver. Clocks must somehow be synchronized; one possibility is to provide a separate clock line between transmitter and receiver. With synchronous transmission there is another level of synchronization required to achieve this, each block beginning with a preamble bit pattern and generally ends with postamble bit pattern. These patterns are control information rather than data. The data plus control information is called a frame. The exact format of the frame depends on whether the transmission scheme is character-oriented or bit-oriented. With character - oriented transmission, the block of data is treated as a sequence of character (usually 8 - bit characters). All control information is in character form. The frame begins with one or more “synchronization characters” Figure (3.20). The synchronization character, usually called SYN, is a unique bit pattern that signals the receiver that this is the beginning of the block. The postamble is another unique character used in some schemes. The receiver thus is alerted to an incoming block of data by the SYN characters and accepts data until the postamble character is seen. The receiver can then look for the next SYN pattern. Alternatively, another approach is to include frame length as part of the control information. The receiver then looks for a SYN character, determines frame length, reads the indicated number of characters, and then looks for the next SYN character to start the next frame.



(a) character – oriented frame



(b) Bit – oriented frame

Figure (3.20) synchronous transmission

With bit - oriented transmission, the block of data is treated as a sequence of bits. Neither data nor control information needs to be interpreted in units of 8 bit characters. As with character - oriented schemes, a special bit pattern signals the beginning of a block. In bit - oriented transmission, this preamble is eight bits long and is referred to as a flag. The same flag is also used as a postamble. The receiver works for the occurrence of the flag pattern to signal start of frame. Some number of control fields, variable length data field, follows this, and finally the flag is repeated. The different between this approach and the character - oriented approach depend on details of the formats and the interpretation of the control information.

3.1.3.7 Interfacing

It is rare to attach a digital data processing device directly to a transmission medium. Referring to figure (3.21) the devices of concern, include terminals and computers, which are generally referred to as data terminal equipment (DTE). A DTE makes use of the transmission system through the mediation of data circuit terminating equipment (DCE) an example of the latter is a modem.

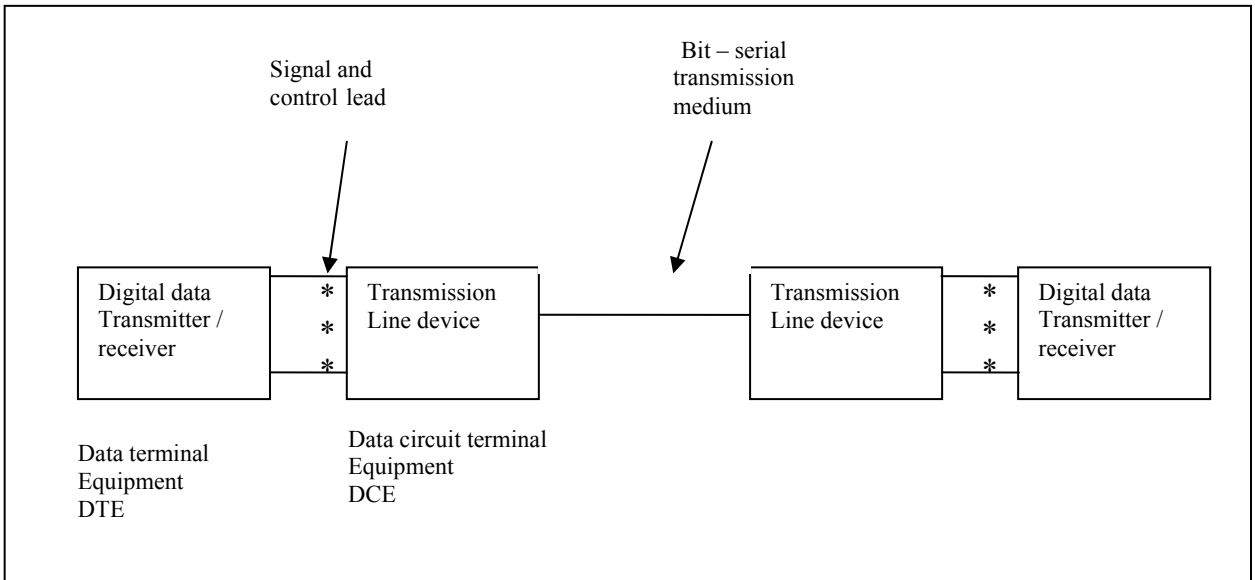


Figure (3.21). Generic interface to transmission medium

On one side the DCE is responsible for transmitting and receiving bits, one at a time over a transmission medium. On the other side the DCE must interact with the DTE, in general this requires both data and control information to be exchanged. This is done over a set of wires referred to as interchange circuits. The two DCEs must understand each other. That is, the receiver of each must use the same encoding scheme as the transmitter of the other. In addition, each DTE - DCE pair must be designed to have complementary interface and must be able to interact effectively to ease the burden on data processing equipment manufacturers and users. Standards have been developed that specify the exact nature of the interface between the DTE and the DCE.

These standards are knows as physical layer protocols, and occupy layer 1 of the OSI model. The interface has four important characteristics.

- Mechanical.
- Electrical.
- Functional.
- Procedural.

The mechanical characteristics describe the actual physical connection of the DTE and DCE. Typically the signal and control leads are bundled into a cable with a terminator plug, male or female, at each end.

The electrical characteristics have to do with the voltage levels and timing of voltage changes. Both DTE and DCE must use the same code, must use the same voltage levels to mean the same thing and must use the same duration of signal elements. These characteristics determine the data rates and distances that can be achieved. Functional characteristics specify the functions that are performed by assigning meaning to the various interchanges circuits. Functions can be classified into the broad categories of data, control, timing and ground.

Procedural characteristics specify the sequence of events for transmitting data, based on the functional characteristics of the interface.

3.1.4 Central Hard Ware

The Central Hardware system is the heart of the monitoring and control system and it comprises the following equipment:

- Central Computer.
- Mass memory subsystem.

- Man-machine computer system.
- Equipment for system maintenance and development.
- Front-end computer subsystem.

Different levels of the hardware configuration are often duplicated to achieve a high availability on system functions, e.g. the main computer system, the front-end computer.

3.1.4.1Central Computer

The Central computer consists of the following main elements:

- Central processing unit (CPU)
- Input / output (I/O) subsystem
- Main memory subsystem
- System software

3.1.4.2 Mass Memory Subsystem

A mass memory is a peripheral device, which is used to make great amount of data quickly and randomly accessible and non-resident. A mass storage peripheral is used as a secondary memory device. Thus the database, operating system and programs are always stored on these devices which usually are high-speed disk drives. Other types of memory devices are the floppy disk and magnetic tape subsystem for long-term storage.

3.1.4.3 Man-Machine Subsystem

Man-machine systems are used to create an efficient working place, by distributing

computer capacity to individual consoles. Man-machine computer greatly increases

the performance of the man-machine VDU interface. It can be used for:

- Performing high-speed communication while fetching static and dynamic information from the database.

- Local storing of static displays (alphanumeric or graphic characters), only dynamic (status indicators, numerical values, etc information is fetched when a display command is initiated.

- Performing high resolution graphics

3.1.4.4 Equipment For System Maintenance And Development.

A computer console is necessary for maintenance of software and hardware as well as computer system start-up. Printers also provide programmers with copies of the programs and data stored in the computers.

The dual, redundant central computer system is the most common configuration used on control centers. There are mainly two concepts used to perform this configuration:

- Master / slave or primary / back-up concept.
- Parallel concept

The master/ slave concept uses only one computer for processing while the other one is on stand-by, ready to take over the operation as soon as the slave computer detects failure events in master computer. This implies that the back-up computer must always be updated. Both computers are usually identically equipped with regards to real-time functions. The man-machine systems are normally connected to the computer currently being master. The master or dedicated communication computers are used to perform RTU communication. The back-up computer takes over RTU communication in the event of a fault in the primary computer.

In the parallel concept both computers work simultaneously, doing exactly the same job, but one is always the master. Transfer in the event of failure is easy because the database in the back up computer is always identical to the one in the master. A drawback with this concept is that both computers are busy during normal conditions and program development, system maintenance, operating etc. cannot be performed in parallel working system as master/slave system unless a third computer is connected.

3.1.4.5 **Front-End Computers**

A front-end computer is a dedicated communication computer, which handles data scanning and transfers the collected data to the main computer as well as handling output from the main computer. A front-end system may also be duplicated, one is normally on-line and the other front-end takes over the scanning on request from the main computer if a failure, e.g. in the front-end itself or in the communication is detected.

3.2 Software Consideration

As discussed previously SCADA systems are built up using computer technology. That is to say that the system consists of hardware and software, and both these factors effect the performance and reliability of the system. When considering software there are at least four main points that must be considered.

- Modularization of software.
- Real-time operating system.
- Programming language.
- Database.

3.2.1 Modularization Of Software

Modularization is necessary in large software system. The natural way to perform modularization of software is to divide it into parts

corresponding to different functions in the system. In SCADA systems, the main functions are data-acquisition, monitoring, control and man-machine communication. The first step in modularization is to specify that each function is performed by one module.

Different modules need to communicate with each other requiring resources such as time memory etc. Unless communication between modules minimized, performance problems will arise. A collection of software modules is usually called a program. A program will communicate with other programs, passing parameters or results or will simply activate other programs. Since the control system must perform many different functions simultaneously there is a need to run several programs simultaneously ensuring that computer resources are utilized efficiently.

3.2.2 Real-Time Operating Systems

In a real time operating system environment a program is called a task (process). A task is a program that has been supplied with various data structure so that the operating system recognizes it as an executable unit.

A real-time operating system is centered around tasks, and the operating system executes different tasks simultaneously. The main functions of a operating system are:

- Resource allocation / sharing between tasks.
- Communication between tasks.
- Input / output handling (BIOS).
- File handling.

A) Resource Allocation And Sharing Between Tasks

The operating system can handle several tasks at the same time. At any instant of time only one program or task can be executed, but most programs will have to stop and "wait" for input / output operations. The purpose of the operating system is to keep the CPU (Central Processing Unit) busy switching between tasks. In this way it appears that the computer is processing several tasks "at the same time". When several tasks are competing for the CPU, the operating system employs a priority scheme to decide which task should be allowed to execute first.
An important part of the operating system is the scheduler, which performs the resource allocation between tasks. The scheduler maintains queues of the tasks in the system, one queue for each possible task state. The goal is always to run the task with the highest priority. Upon activation the scheduler scans its queues to find out if there is a task with higher priority then the executing one.
If that is the case, the running task is halted, but in a queue the task with the higher priority is started.

B) Communication Between Tasks

There are several ways to let tasks communicate with each other. A common method, often used in control system applications, is to communicate indirectly via a global database. In order to provide a direct communication method, most operating systems include channels, which are abstract entity, which accepts messages from one task and forwards these messages to another task.

C) **BIOS - Basic Input / Out put System**

Operating systems include a set of functions for device independent input / output operations. A request for input or output should be independent of specific physical devices. Instead all input and output is performed on logical files.

The software that actually performs the input / output operation on the physical device, is called a handler or driver. Each kind of device usually requires a specific handler / driver so if a new kind of device is going to be used in a system a new handler / driver must be written. It must be noted that all handler / drivers are associated with the BIOS.

D) **Program Development Support**

To be able to develop new programs, and to maintain old ones, several system programs are necessary.

- Editor
- Compilers
- Linker
- File manager

An editor is a program that permits writing program source code interactively. There are two basic types of editors, line-oriented and full-screen types. Since VDU terminals are usually used, full-screen editors most common used.

A compiler is a program that transforms source code in a high-level language into machine code. The machine code (object code), is not directly executable by the computer. A linker must first process the code. A linker is a program that processes the object code generated by the compiler and links the object code with library programs. The output of the linker is a code that can be directly executed by the computer, usually called executable code.

File manager organize all information stored in secondary files in a convienient and efficient way.

3.2.3 Programming Language

The programming language has a great impact on both performance and reliability in SCADA systems. In the early days of computer applications assembles or machine languages were the only choice. An assembler language includes instructions that operate directly on the CPU registers, memory-cells etc. in the computer. The programming takes place on a very low detailed level. Nowadays high-level languages (Basic, Pascal.. etc.) are used in the implementation of SCADA functions.

3.2.4 Database

As the volume of data processed in computerized control center applications are continually increasing, it is necessary to include database systems in the design of such systems. Introducing a database in the design will lead to the following advantages:

- Organized structures of data are established.
- Data are stored with very little redundancy, i.e. in only one place, with flexibility in the selection of storage medium.
- Data access is done by a central access-routine providing data security.
- Study databases are easily introduced as a tool for simulation studies.
- Control systems software consists of large number of different programs that needs access to a large volume of data. Even though different programs perform different functions, they often use the same data as other programs, or produce data that is used by another program. A data is therefore an important part of the control system. There are several requirements of a database system for relative applications. These can be summarized as follows:

- Logical access: Programs must be able to read/write in the database in a standardized way.
- Protection: The database system must protect itself against hardware errors and program errors.
- Conversion: Data must automatically be converted and sealed to the units requested by the caller.
- Speed: Access to the database must be fast.

In computer, all data must be stored in some format that can be handled by a memory device. There is a physical database structure and a logical data base structure and the database system must be able to make translations between the two, refer to Figure (3.22).

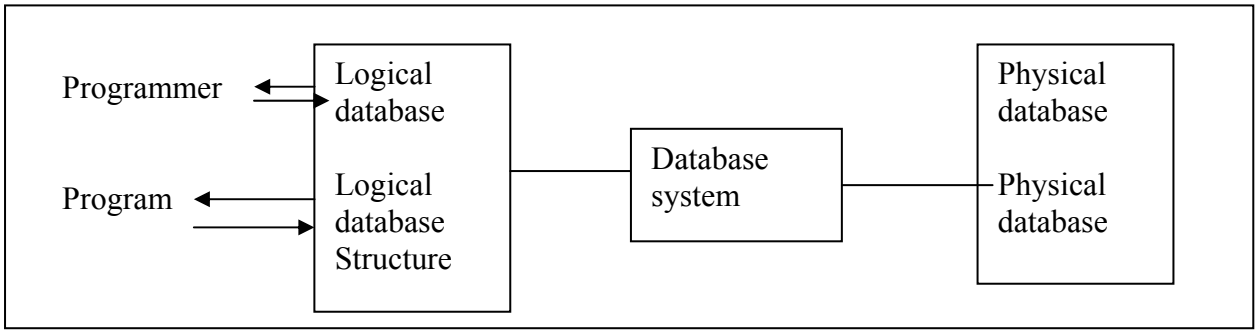


Figure (3.22) Structure of data base system.

A database can be thought of as a model of a certain part of reality. The modeling concepts are objects, attributes, relations and time. All objects, physical or abstract, can have attributes. There can be relations between objects and all these three concepts can be functions of time. A logical database structure is defined in terms of these concepts. There are three different basic ways of organizing logical database structure.

- Hierarchical
- Relational
- Network

The hierarchical type may be though of as a tree where relations or connections exist between objects on one “level” to an object on other level. A relational type can describe any relation between objects, not just “levels”. A network type of database has a very natural application in power system control systems. The physical data base structure depends on what type of memory is used.

CHAPTER FOUR
IMPLEMENTATION OF SCADA FUNCTIONS

The ambitious purpose of this chapter is to describe the practical steps in building a system resembling the state of the art on a small scale .The approach was to build the blocks discussed in previous chapters bearing in mind that the SCADA system must perform effectively and reliably as an operational system in an operating environment; this goal must be obtained by a well engineered and integrated hardware/software. A logical approach to the SCADA system implementation is to define and develop the functions that must be performed. These functions are listed as follows :

Data acquisition.
Database.
Operating system.
Man-machine interface.

Interrelation-ship of these functions with due consideration for the state-of-the-art hardware and software constraints is shown in Figure (4.1).

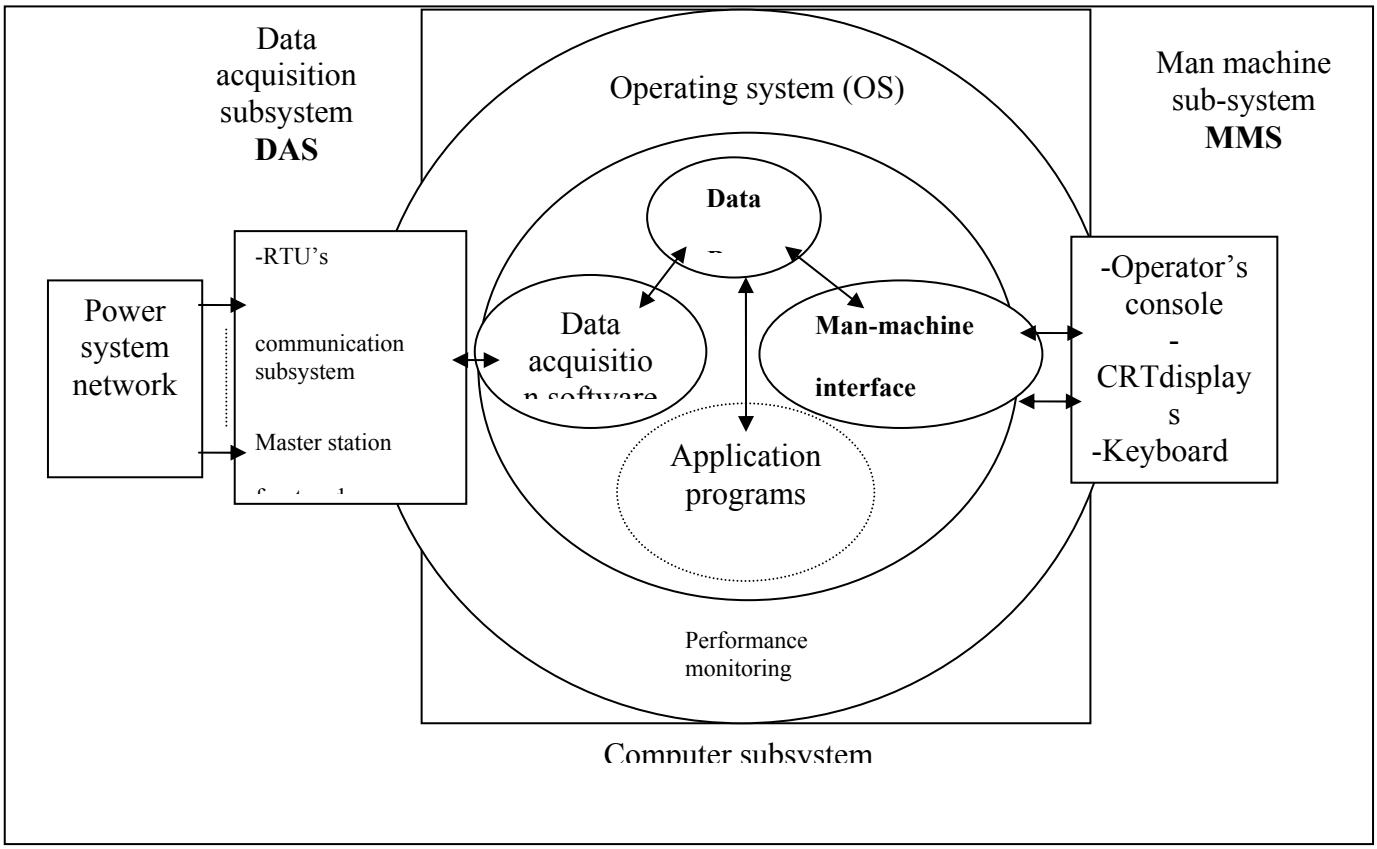


Figure (4.1) SCADA functional Diagram

4.1 Project Needs

The project needs were estimated as follows :

1- Two powerful PC computers at least ; one to be located as a remote terminal unit (RTU) and the other located in the control room.
2- Two data terminal units (modem) to perform communication between the (RTU) and the centeral computer .
3- A data aqusition card to collect RTU signals and perform analog to digital conversion.
4- Programming software to implement SCADA functions .
5- Operating system package.

4.2 Interface And Data Acquisition

The interface and data acquisition function was required to :

1. **Interface the power system data measurement signals to the RTU through a data acquisition element . These signals are collected from a transducer panel within a range of 0-5 mA. Appendix (A)describe the desired signal specifications and wiring connections .**
2. **Perform signal conditiong between the panel signals and the data aqusition element .**
3. **Detect and handle data error conditions due to noise.**
4. **Scale and convert analog data into a form usable by computer programs.**
5. **Interface with the Database Manager (DBM).**
6. **Store only good (error free) data in the database.**

4.2.1 Data Aqusition Card

The ADAC 5500MF data aqusition card was used in collecting signals from a transducer panel. The 5500MF is a half size module with 8 high level (±10Volts) differential analogue inputs multiplexed to a 12-bit A/D converter. Total hardware conversion time is approximately 30microseconds. Figure (4.2) shows the card block diagram.

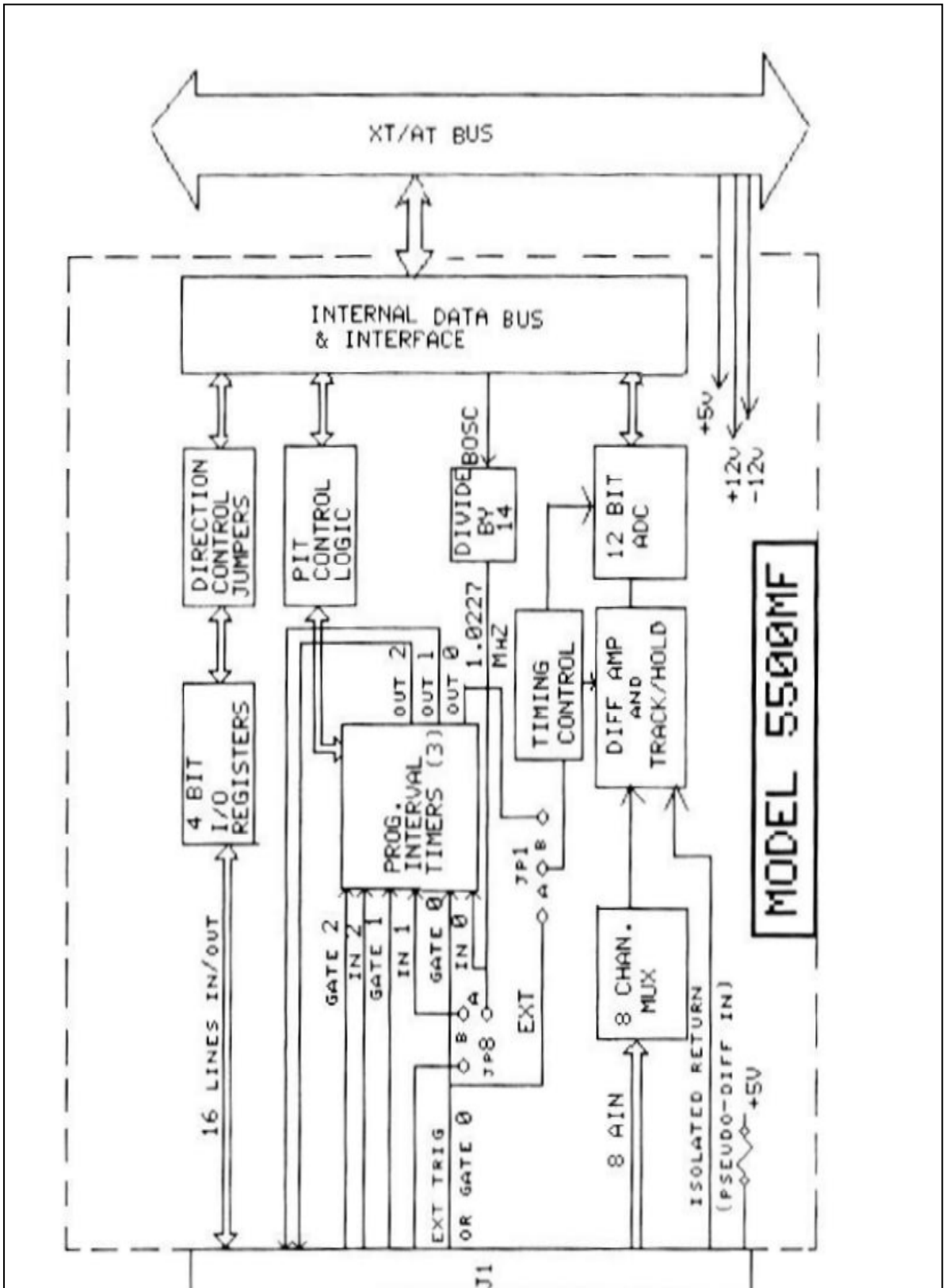


Figure (4.2) card block diagram

4.3 Analog To Digital Converter

The analog to Digital Converter (ADC) section consists of an 8 channel input multiplexer, a track/hold circuit referenced to local ground or to an externally provided input common, the actual A/D converter, timing and trigger circuits.

An analog to digital conversion can be initiated and performed as follows :

- Write control word to A/D CSR (control and status registers)
- Wait for A/D completion
- Read A/D data

The following example shows a code written by C language to perform the A/D convertion .

```
/* write A/D CSR */
OutP (BaseAddress + 0x09, ADCSR>>8);
OutP (BaseAddress + 0x08, ADCSR);
While ((inp (BaseAddress + 0x08) & 0x80) = =0);
Variable = ( inp (BaseAddress + 0x0B)<<8 & inp (BaseaAddress + 0x0A);
```

The example indicates that the control and status register (CSR) allows software configuration of operating parameters and indicate status of various portions of the A/D . The CSR is defined in two bytes low at **Base + 08H** and high at **Base + 09H**.

The low byte CSR contains control bits. These are

BTT 7 – DONE (READ ONLY) : This bit sets when the A/D completes the current conversion indicating fresh data is available. This bit is cleared when the A/D data buffer is read.

BIT 2 – 6 : not used

Bit 1 – TREN : (Read/Write) : enables external triggering of the A/D.

Bit 0 – GO : (Write only): used for software triggering of the A/D when set high.

Bit 0 – Busy **:(Read only): goes low in response to an A/D trigger, and returns high at completion of the A/D conversion. The high byte CSR selects the analog input channel.**

Bit 3 – 7 :not used

Bit 0 – 2 :Mux bits (Read/write) : Channel selection bits for the A/D input multiplexer.

Data is right justified, i.e. 8 least significant bits are in lower byte with bit 0 being least significant bit. The 4 most significant bits are in the upper byte bits 0 – 3.

A/D data lower byte (Base + 0AH)
A/D data upper Byte (Base + 0BH)

4.4 Software Implementation

Data acquisition functions were implemented to perform the following operations.

1. Scan raw data from a transducer
2. Check data for errors and consistancy against operating limits
3. Scale and convert the analog measurement.

Next the RTU software, maps data into a database file. The software was designed generally to perform analog data scanning and database updating.

4.5 The Choice Of Programming Language

To implement the Data Acquisition functions the choice was highly focused on Visual Basic programming language as a programming media.

4.5.1 History Of Visual Basic

In 1991 Microsoft released Visual Basic 1.0. Visual Basic was created in order for developers to develop Windows applications quickly. Visual Basic was not a completely new language . Its origins came from BASIC or Beginner's All-purpose Symbolic Instruction Code, which was designed, in the early 1960's. One of the big differences between BASIC and Visual Basic is that Visual Basic can create Windows programs where BASIC can only create DOS programs. Another improvement with Visual Basic was the ability to create user interfaces effortlessly. Unlike other languages where the programmer has to code how big the form is and where the command buttons will be, with Visual Basic a user is able to "draw" these on.

4.5.2 Characteristics

The event-driven model was maybe one of the biggest advances for Visual Basic. Before in BASIC a programmer had to program to watch for users when they had a mouse click or a certain key was hit.

4.5.3 Size:

Visual Basic contains many keywords and functions built in. This makes it a fairly large language.

4.5.4 Development Time

Visual Basic was built with the idea of fast development. The time it takes to build a fully functional application in Visual Basic can be quite small when compared to other languages. Visual Basic has made it possible for applications to be developed rather quickly.

4.5.5 Learning Curve

Visual Basic is one of the easier languages to learn. It does not contain the complex data structures and data manipulation capabilities of Visual C++. This is a limiting factor in some ways but it is possible to do most things with Visual Basic that can be done with Visual C++.

4.6 Implementation Of Database Desing

The ingredients of database implementation was classified into four task areas.

1. Content and naming convention of the database.
2. Database accessing methods.
3. Structure of the database
4. Database manager software

4.6.1 Content And Naming Convention

The first point of consideration is the content of the database. A definition of all data item names and descriptions of every data item needed in the system must be made.

For power system data, the quantative definition of data can best be done on a station basis, i.e. for each generating, transformer, and switching station, all of the data items for the following data types could be identified

1.Voltages.
2.Line and station Mw and Mvars.
3.Transformer tap positions.
4.Breaker positions.
5.Disconnects and grounding switch positioning.
6.Capacitor banks.
7.Security status.
8.Alarm status.

For each data item in the above list of data types, the following characteristics could be defined.

1.Data item name.
2.Description of data quality.

3.Accuracy – transducer and ADC.
4.Resolution / precision.
5.Error rate statistics.
6.Range of values.
7.Scaling and conversion factors.

Related to the content of the database is the naming convention of its individual elements.

A good naming convention should greatly simplify database maintenance and the use of the database by application and system programers. The following data attributes should be included for power system data :

1.Station name and kV level
2.Equipment name of ID
- *Trasmission line*
- *Transformer*
- *Capacitor bank*
- *Breaker*

3.Operating quantity
- *kW*
- *mVAR*
- *mW*
- *Frequency*
- *Status*

4. Data Characteristics
- *Measured via data acquisition*
- *Computed or filtered by application program*
- *Manually entered by system operator*

4.7 Database Maneger

Database Manager (DBM) is a software package which is part of the executive software and may be integral to the operating system.

The operation of the DBM is categorized into four general functions:

1. Maintenance of directories of all data points stored in the data base. The directories contain the attributes of each data point necessary for efficient data location and processing. These attributes include the elements symbolic names, memory addresses, storage format.

2. Control the physical layout of the data base in memory. This function includes determing where a data point is stored and its relative address.

3. Additions and detectors of data elements from the data base.

4.Interface all computer operations with the data base. The primary concern of this function is to maintain a consistent data set within the database and provide programs requesting data with consistent data subsets, this function includes providing the necessary read/write locks for security of the data base.

To maintain the above requirement SQL was used in implementing the data base function.

The Structered Query Language is a language for accessing data in a relational database. Originally created by IBM, many vendors developed dialects of SQL.

Early in the 1980's, The American National Standards Institute (ANSI) started developing a relational database language standard. ANSI and the International Standards Organization (ISO) published SQL standards in 1986 and 1987, respectively.

4.8 Operating System

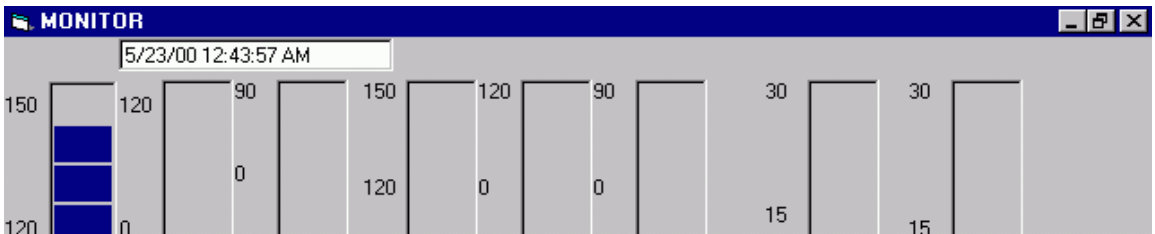
For state-of-the-art SCADA system and control centers, the operating system (OS) is normally implemented by revisions and add-ons to the latest version of OS for the computer system selected. The primary reason for this approach is the prohibition software cost of developing and maintaining a new OS optimized for SCADA system.There for the purposes of this project choice was focused on using Windows 95/98 and Windows NT as an operating system to benefit from its networking communication features.

4.9 Man-Machine Interface

As user interface plays an essential part of the monitering system , and great care was made to implement the user interface .

Figure (4.3) shows the main monitoring screen, which will graphically represent the main readings.

As could be seen below in figure (4.3) the main monitor shows the date and the time and the readings that transmitted both to the database on the server as well as to the main mointoring screen.



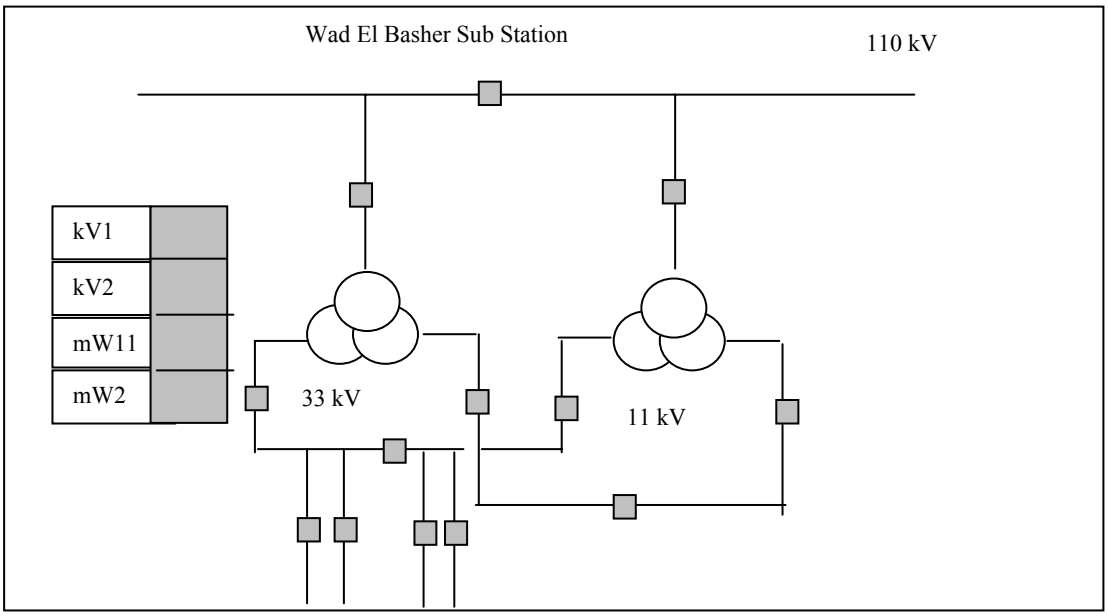
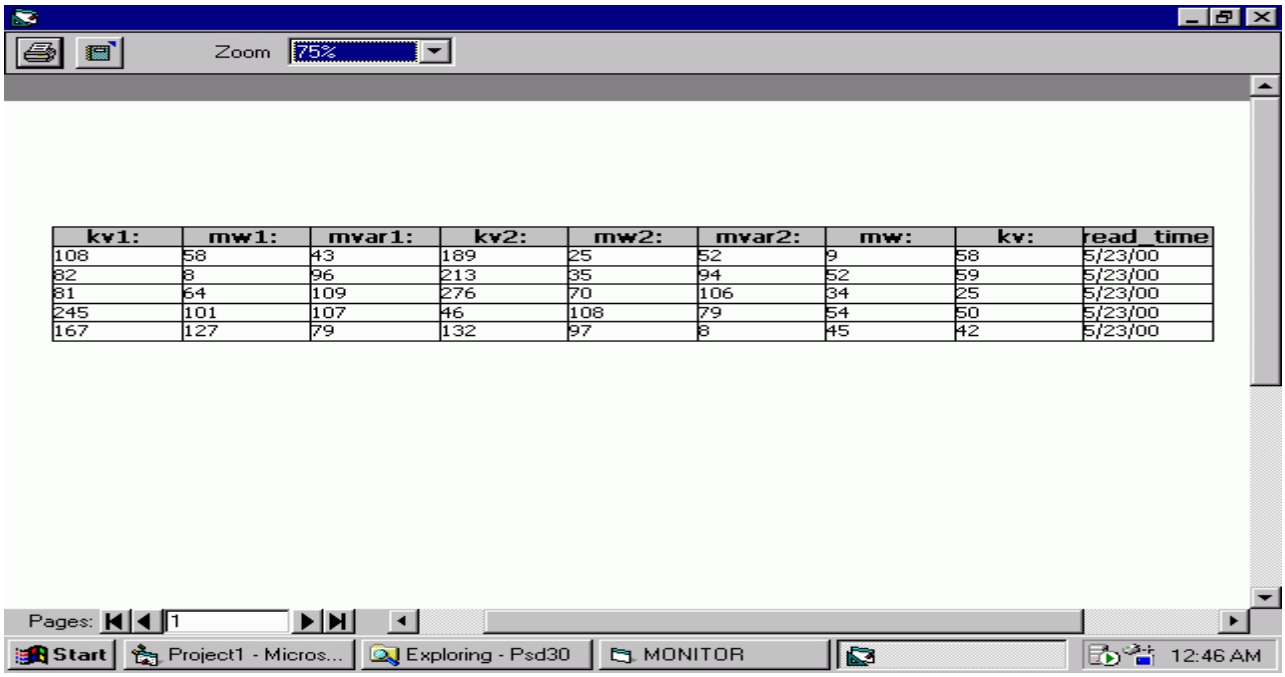


Figure (4.3) main monitoring screen

Figures (4.4) shows the generated report, the report displays the readings and the exact time at which each reading was taken.



kv1:	mw1:	mvar1:	kv2:	mw2:	mvar2:	mw:	kv:	read_time
108	58	43	189	25	52	9	58	5/23/00
82	8	96	213	35	94	52	59	5/23/00
81	64	109	276	70	106	34	25	5/23/00
245	101	107	46	108	79	54	50	5/23/00
167	127	79	132	97	8	45	42	5/23/00

Figure (4.4) a generated readings report

4.10 Comments

Within this research effort , a small computerized monitoring and control system has been put into operation to represent the use of computers in power system monitoring and control. The system can be applied to a variety of applications in plant system such as generating stations, control centers on various hierarchial levels in power transmission, control centers for municipal and district distribution as well as computerized management applications. At the same time the model represents the use of personal computers with few input signals that can be extended to design a complex supervisory control system.

Looking upon the project schedule, there were many hurdles that caused problems and delayed delivery schedules; one is that the project needed a high degree of involvement from many departments of the National Electricity Corporation which initially was not foreseen.

Another reason is that a new utility and innovative system is often faced by the lack of information resources and technical support .

This section will illustrate some technical experience gained through the research. A complete survey of the system in operation may be in practice unweildly. Thus, the section will give some general remarks regarding control center implementation to reflect the state-of-the-art as outlined in the previous chapters.

Generally speaking the introduction of computerized control centers brings a better and faster supervision compared to the slower manual system in the network. The operation and operations planning routine will be rationalized due to the use of automated technology.

The system design can be easily extended to provide both SCADA system and energy management systems (EMS) services.

However, the border line between SCADA systems and EMS is vague and always moving.

Hierarchial control center will sooner rather than later be urgently required in the development of the Sudan National Grid; the reason for this is the ongoing expansion on the level of demand as well as the ongoing policy to introduce many companies in the field of power production.

This means that global system functions well be integrated and allocation of various functions to different control centers must be performed from a system design point of view, this is done either as an integration into the same computer system or as separate computer systems connected to each other over a communication network .

As mentioned through this research, the traditional control room and the operators work philosophy will change as a consequence of installing computerized control centers.

As the power network tend to increase the number of operator's consoles and vdus will increase. Although mimic boards will still be used, the concept of mimic will change to give a general over view of the most important information .That will simply means that the "Control room" in larger systems is not longer a single room but is geographically spread out; i.e. operator work places (consoles) will be connected to the computerized control centers from different remote locations that development must impose new operational routines on the utility and stresses the need for service operation.

A general layout of the control center configuration is given in Figure (4.5). The control system computer configuration will

always vary between different installations and different approaches of designers but some similarities can be identified. The main computers will always be assisted by one or more front-end computers or “intelligent” communication interfaces based on microcomputers performing the data acquisition.

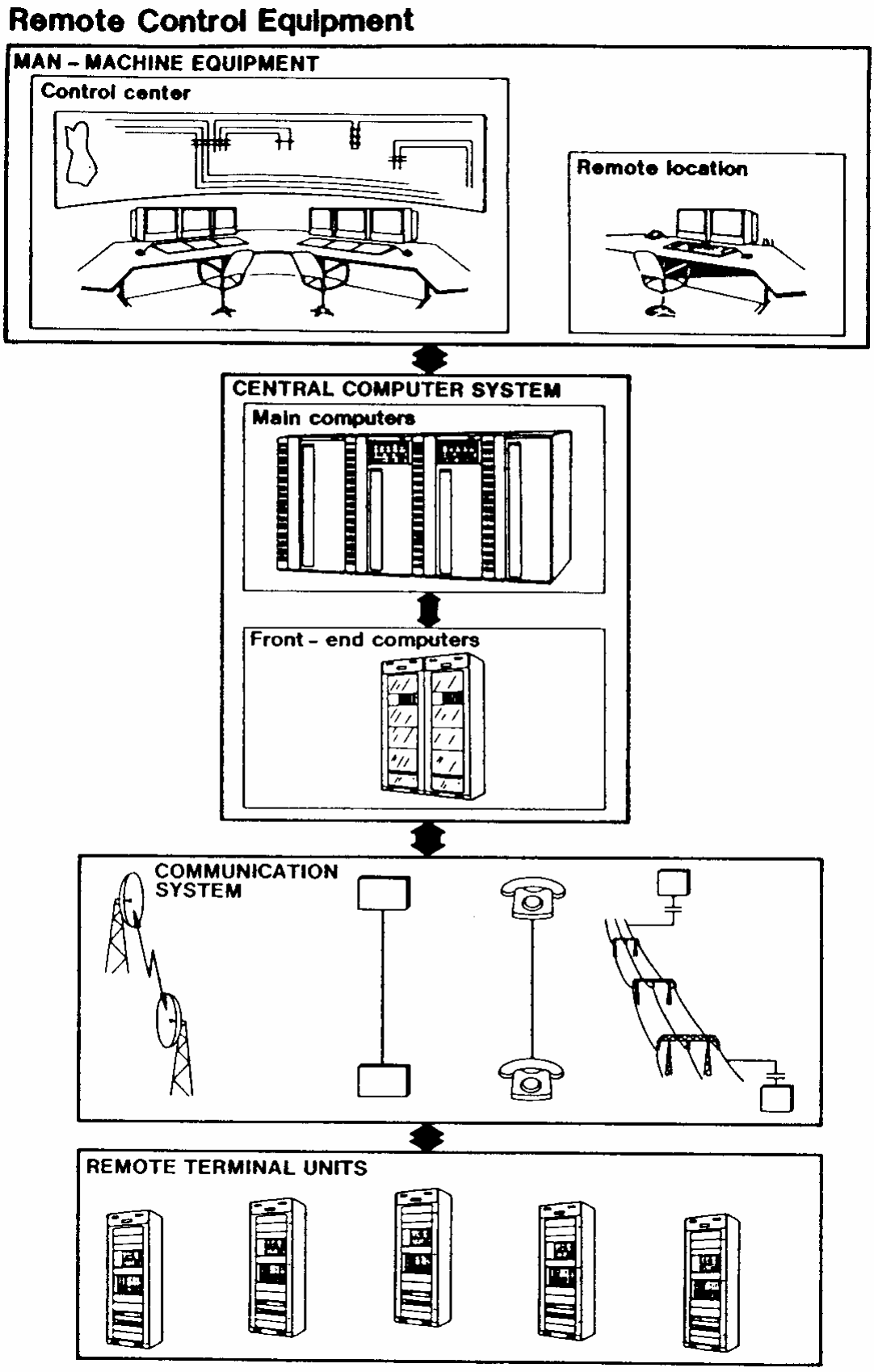


Figure (4.5) control system configeration

The communication network for acquiring data from the substation and power stations has a promising future due to the modernization that had been made to the public communication media.

The RTU's in the substations and stations , which are always based on microprocessors, will see a major development in its functions due to the changes made in the field of microcomputer. As a result these changes will be clearly noticed in the integration of RTU's functions into the in-plant computer.

Finally, when discussing general technical aspects on control center implementation, the importance of the so-called auxiliary system needs to be stressed. Experience shows that one of the major reasons for malfunctions in the computerized system during a disturbance is due to negligent design of the auxiliary systems. If the power supply systems is not designed with care, there is a great risk that the utility cannot benefit from its computerized system in the event of a black-out. Thus, the power supply system must often comprises a concept or redundant rectifiers, batteries and inverters, sometimes even combined with diesel generator.

CHAPTER FIVE

CONCLUSIONS AND FUTURE ASPECTS

5.1 Project Evaluation

Throughout the practical steps of this study a small computerized model has been designed and operated to test the introduction of automation technology in a classical power network. The model which has been carried out at Wad El Basher substation using the building blocks listed in figure (3.1) and the simplest point to point communication polled mode configuration proved that simple real time monitoring of electrical measured quantities can be achieved at the central station using SCADA technology concepts.

Throughout the practical work many problems have been raised which highlight the weakness of the designed system and must be considered with great care. These problems can be summarized as follows together with recommendations for their solution.

- **Data acquisition board was subject to some degree of noise pickup from power lines and transformers at the substation. Therefore it is important to use signal conditioning to ensure rejection of noise and blockage of voltage surges to avoid damages to the DAQ board [refer to section 3.1.1.2.b at chapter three].**
- Hard disk failure was a common problem causing loss of software code source and data, therefore it is important to keep a copy of the source code and backup of data using proper method of backup (backup hard disk, backup tape, compact disk …etc).
- Hardware failure also was a common problem facing the study due to low component quality, therefore only genuine parts is highly recommended in the design of such type of system to avoid unstable operation.
- Telephone line noise leads to error in data received at the central station; the key to success here lays in the use of cheap but reliable data communication links to avoid data corruptions such as leased lines.

The study proved the possibility of introducing SCADA functions to the infra-structure of the electrical supply network of the Sudan National Grid. This will not only ensure reliable monitoring of the network as mentioned at chapter one but also the integration of the power process with monitoring and control systems will improve the level of the system operation reliability since corrective actions to restore power system rapidly could be achieved.

The development of the National Grid is highly coupled with the introduction of automation process. Integration of distributed substations into a computerized monitoring and control system will lead to better supervision that will provide a clear image of the current loading situation and immediate fault locations. In this way it is possible to locate fault quickly, analyse the fault, study the correct sequence of events leading to the fault. This is possible because logged data is time –stamped, and time resolution is limited only by the sampling interval of data acquisition card. The data describing the measured system quantities are relayed immediately to the control database where they are temporarily buffered. Clearly, since the data is real-time logged, the amount would in a short time be overwhelming and must be discarded. For postmortem analysis of system disturbance only the few seconds leading to the critical event need to be examined. The data collected through the monitoring process is thus divided into two sets; a permanent time stamped log of system variables entered at regular intervals of five minutes separation and real time- stamped set of data that logs the system variables within the last five minutes interval. This data is maintained as a constant length stack where new data at the head of the stack replaces outdated information at the tail of the stack.

Relation between production and consumption could be always kept at balance since load management functions are an essential part of automated monitoring and control systems.

Maintenance functions which rely on the statistics of system reliability will be more effective since information for components requiring maintenance will be available.

Great care must be focused on the operators to prepare them to make quick decisions in situations where they work under stress, and the

information provided through the monitoring process will help improving operators skills to keep normal state as long as possible.

The introduction of automated systems also will help traditional based engineers with the problem of controlling and dealing with new technology and computerized consoles.

5.3 Concluding Statement

A small model has been developed and operated to show how SCADA systems will help improving Sudan National Grid network and it is hoped that future efforts are put forward to complete this model to the full level of SCADA functions noting in particular that microcomputers will spread out into the power industry paving the way for new technical solutions.

EFERENCES

1- Albert Paul Maliveno, PhD. : " Digital Computer Electronics, An Introduction To Micro Computers", Second Edition, Tata Mc Graw-Hill Publishing Company Limited, New Delhi 1991

2-Client/Server Application. : "Australian Personal Computer Magazine", August 1996.

3- Editor Choice Collection. : "Topics In Visual Basic ", Macmillan Publishing1998, Macmillan, Host: www.mcp.com/resources/programming/msdeveloper/visual.basic/ec.vb/

4-James J. Broly. : " Basic Electronic For Scientists", Forth Edition, Mc Grow Hill 1983.

5-Jacob Millam & Christb C.Halkias. : " Integrated Electronics Analog And Digital Circuits And Systems", Mc Graw-Hill Book Company 1972

6- Lewis C. Eggbrecht. : "Interfacing To The IBM Personal Computer Notes "

7-William Stallivgs. : " Data And Computer Communications", Forth Edition, Mac Millan 1991

8-Taking The Digital Approach To Protection. : "Middle East Electricity",The Journal For Power Management, May/June 1998.

9-"The Booket Book Of Commputer Communication ", Second Edition, Gray Communication 1998

10- Torsten Cegrell. : "Power System Control Technology ", Prentice/Hall International (UK) 1986.

11. "measurement and automation catalogue" , national instruments . (1999) 215-221.

System – Bus Signal Description and Definitions

OSC (Oscillation)

This is an output signal with a period of approximately 7 ns. It is the highest frequency signal on the bus and all other timing signals are generated from this signal care should be taken when this signal is used to clock other bus signals, since bus delay effectively desynchronizes this signal with respect to other bus signals.

CLK (Clock)

This signal is an output derived from the OSC signal. It is a well synchronized with respect to the memory read and memory write controls and it can be used to generate system bus wait states.

RESET DRV (Reselect driver)

This out put signal is held active high during system power on sequences. It remains active until all levels have reached their specified operating range and then it goes in active. If any power level falls outside its specified operating range after power on this line is brought high. This signal is used to provide a power on reset to bus attached interface logic on I/O devices to bring them to a known state before operation by the system. This signal is set active and inactive on the falling edge of the OSC signal. Due to logic delays, this synchronization should not be relied for any attachment design.

Ao Through A19

Address bit Ao through A19 are output signals that are used to address system bus attached memory and I/O. These 20 signal lines are driven by the processor during system bus cycle for memory and I/O read and write. They are driven by the direct memory access logic feature during DMA cycles. The processor, through the use of the IN and OUT instructions, can address up to 64K I/O port addresses. These port addresses are also carried on the address bus on lines Ao through A15. Lines A16 through A1a are not used and are held inactive during I/O port bus cycles. On personal computer, only address lines Ao through A9 are used for addressing I/O port. In addition only I/O port addresses in the range 0200 HE X TO 03 FF HEX are valid on the system bus. Reference to APPENDIX C.

Do through D2

These eight lines are bi directional data lines used to transmit data between the processor, memory and I/O, and I/O ports, during the processor write bus cycle, data are presented on the bus for writing into memory or I/O ports. Data are valid slightly before the back rising edge of the IOW or MEMW control signal. The rising edges of these signals are usually used to clock the data on the data bus into memory or I/O port registers. During processor initiated read bus cycles, the addressed memory or I/O port register placed their data on the data bus before the rising edge of the I/O or MEMER control signals. During direct memory access cycles, the data bus is used to transfer data directly between an I/O port and memory without the intervention of the processor. During the DMA cycles, the processor is disconnected from the bus and the direct memory access controller controls the bus transfer.

ALE address latch enable

This output only signal is driven from the bus controller, it is used to indicate that the address bus is now valid for the beginning of a bus cycle. The signal goes "active high" just prior to the address bus being valid and falls to "inactive low" just after the address bus is valid.

I/O CHCK (I/O Channel check)

This is a low level input only signal used to report error conditions on the bus attached interface cards when this signal set low it generate a non mask able interrupt (NMI). The NMI is actually masked by an I/O register port bit and must be enable before the interrupt can be received by the processor.

I/O CH RDY (I/O channel ready)

This input signal is used to extend the length of bus cycles, so that memory or I/O ports that are not fast enough to respond to a normal bus cycle can still be attached to the system bus. If a memory or an I/O port wants to extend the bus cycle it will force the I/O CH RDY line low when it decodes its address and receives a MEMR, MEMW, IOR or IOW command.

IRO2 – IRQ7 (interrupt request 2 through 7**).**

These six input only signals are used to generate interrupt requests to the processor from the system bus.

IOR (I/O Read)

This is an output signal from the bus controller. It is used to indicate to the I/O ports that the initiated bus cycle is an I/O port read cycle and that the address on the address bus is an I/O port address. The I/O port address should respond by placing its read data on the system data bus. This signal is active low when a direct access cycle occurs the IOR signal is driven from the direct memory access (DMA) controller on the processor board.

IOW (I/O write)

This signal is a low level active out put only signal. It is driven from the bus controller during the processor initiated bus cycle and indicates the address bus that contains an I/O port address and that data bus that contains data to be written into the I/O port when a DMA bus cycle occurs, this signal is driven from the DMA controller. The IOW signal is then used to write data from memory.

MEMW (Memory write)

This is a low level active signal used to write data from the system bus into memory. This signal is driven from the

processor bus controller during the initiated bus signals and indicates that the address bus contains an address of a memory location to which the data on the data bus are to be written. During DMA cycle this signal is driven from the DMA controller and is used to write data on the bus from an I/O port into memory.

MEMR (memory read)

This signal is a low level out put signal used to request road data from memory. This signal is driven from the processor bus controller on the initiated bus cycles. It indicates that the address bus contains a valid memory read address and that the specified memory location should drive the system data bus with its read data. During the DMA cycles this signal is driven from the DMA controller and indicates that the address memory location should respond by driven the data bus with its read data.

DRQ1 through DRQ3 (direct memory access request 1 through 3)

These three lines are active high input only lines used by the interface to request DMA cycles. If a device or interface logic want to transfer data between itself and memory without the intervention of the processor the request is initiated by raising a DRQ line.

DACK0 Through DACK3 (Direct memory access acknowledge Q through 3)

These four signals are low level active output only signals issued by the DMA controller to indicate that the corresponding DRQ has been honored and the DMA controller will take the bus and proceed with the requested DMA cycle.

AENE (Address enable)

This signal is an output only active high signal issued by the DMA controller logic. It indicates that a DMA bus cycle is in progress. This signal enable controlling the bus from the DMA controller.

TC (terminal count)

This signal is an output active high signal issued by the DMA controller, it is typically used to terminate a DMA block data transfer.

Bus power AND ground

Figure ( ) illustrates the signals present on the system bus in addition the system contains the following power level (± 5 VDC, ± 12 VDC, GND) .

System I/O MAP

I/O address are used in interface designs as well as system memory address. We will concern here with the I/O map, further information can be found in IBM PC technical reference.

PC PORT ADDRESS MAP

PC/XT	
I/O ADDRESS (HEX)	**DESCRIPTION**
000-OFF	**Do not use**
100-1FF	**Uncommitted**
200-207	**Game Port**
208-20F	**Uncommitted**
210-217	**PC and XT expansion chassis**
218-21F	**Uncommitted**
220-24F	**Parallel Printer Port 2 (LPT2)**
280-2EF	**Uncommitted**
2FO-2F7	**Reserved**
2F8-2FF	**Serial Port 2 (COM2:)**
300-31F	**Prototype Card**
320-32F	**Fixed Disk Controller (XT)**
330-377	**Uncommitted**
378-37F	**Parallel Printer Port 1 (LPT1:)**
380-38F	**SDLC Communications**
390-39F	**Uncommitted**
3AO-3AF	**Reserved**
3BO-3BF	**Monochrome Display and Printer Adapter**
3CO-3CF	**Enhanced Graphics Display Adapter (EGA)**
3DO-3DF	**Color Graphics Display Adapter (CGA)**
3EO-3EF	**Reserved**
3FO-3F7	**Diskette Controller**
3F8-3FF	**Serial Port 1 (COM 1 :)**

PC PORT ADDRESS MAP

PC/AT	
I/O ADDRESS (HEX)	**DESCRIPTION**
000-OFF	Do not use
100-1EF	Uncommitted
1FO-1F8	Fixed Disk Controller
1F8-1FF	Reserved
200-20F	Game Port
210-277	Uncommitted
278-27F	Parallel Printer Port 2 (LPT2:)
2E8-2EF	Serial Port 4 (COM4:)
2FO-2F7	Uncommitted
2F8-2FF	Serial Port 2 (COM2:)
300-31F	Prototype Card
320-35F	Uncommitted
360-36F	Reserved
370-377	Uncommitted
378-37F	Parallel Printer Port 1 (LPT1:)
380-38F	SDLC, Bisynchronous Port 2
390-39F	Uncommitted
3AO-3AF	Bisynchronous Port 1
3BO-3BF	Monochrome Display and Printer Adapter
3CO-3CF	EGA or VGA
3DO-3DF	Color Graphics Display Adapter (CGA)
3E0-3E7	Reserved
3E8-3EF	Serial Port 3 (COM3:)
3F0-3F7	Diskette Controller
3F8-3FF	Serial Port 1 COM 1:)

APPENDIX A

TRANSDUCER PANEL BLOCK DIGRAM

APPENDIX B

SYSTEM BUS SIGNAL DESCRIPTION AND DEFINITIONS

APPENDIX C

PC PORT ADDRESS MAP

APPENDIXES